In the prime of life: ERP evidence for syntactic comprehension priming in older adults

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Abstract. *Background:* Recent studies suggest older adults' implicit learning of syntactic patterns remains largely intact. Syntactic priming has proven to be a sensitive tool to examine this implicit sensitivity. However, most priming studies with older adults have focused on production, and none have included an electrophysiological component. This study explores the neural correlates of syntactic priming in older adults' comprehension. *Method:* We used a self-paced reading and event-related potential paradigm with groups of older and younger adults. Reduced Relative targets were primed, unprimed, or lexically boosted, while reading times and EEG recordings were obtained. Pre-tests of Working Memory and Processing Speed were also recorded. *Results:* Older adults showed intact priming and lexical boost on reading times, while lexical facilitation was dependent on syntactic overlap in the older but not the younger group. Syntactic priming was evident on N400 and P600 modulations on verbs and nouns in Reduced Relatives, and generally did not differ by age group. This suggests older adults may be susceptible to syntactic facilitation in the same ways younger adults are, and makes the case for more non-declarative, electrophysiological measurements of older adults' sentence processing ability in future studies.

Keywords. dementia; interactional sociolinguistics; multimodal analysis; aging; communication

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1 Introduction

With great age comes great wisdom. However, most studies of sentence comprehension in healthy older adults have emphasized the declining nature of comprehension. These deficits are seen either as a consequence of impaired Working Memory capacity (hereafter

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WM; e.g., Norman, Kemper, and Kynette 1992; DeDe et al. 2004; Waters and Caplan 2001), of Processing Speed limitations (e.g., Salthouse 1996; Salthouse and Babcock 1991), or of some age-specific decline unrelated to memory or speed demands (e.g., Poulisse, Wheeldon, and Segaert 2019). Following much of the sentence comprehension literature, therefore, great age brings impairments and declines.

Nevertheless, numerous recent investigations have reported little to no age-related difference on various sentence comprehension measures (Hardy, Messenger, and Maylor 2017; Hardy, Segaert, and Wheeldon 2020; Hardy, Wheeldon, and Segaert 2020; Malyutina et al. 2018; van Boxtel and Lawyer 2023). This recent increase in reports of age-invariant sentence comprehension seems to be associated with a general shift from the use of declarative measures, such as paragraph comprehension and sentence recall scores, to implicit paradigms, including priming, eye-tracking tasks, and Event-Related Potential (ERP) recordings (e.g., DeDe 2014; though cf. Huang, Meyer, and Federmeier 2012). Additionally, findings of older adults' successful compensation for potentially impaired cognitive functions using other, unimpaired functions have raised questions about the extent to which language ability, and sentence processing in particular, is subject to similar compensatory processes. For instance, older adults recruit wider neural resources compared to younger adults during engagement in cognitive tasks, potentially resulting in more preserved performance (Peelle 2019; Morcom and Johnson 2015). In terms of language processing, some studies have found evidence for the use of semantic information as a compensatory strategy for syntactic processing deficits (e.g., Poulisse, Wheeldon, and Segaert 2019). Alternatively, the slowing of linguistic and cognitive operations seen in older adults could, in fact, be a compensation mechanism itself, allowing more time to complete these operations (e.g., Salthouse 1996; cf. Malyutina et al. 2018).

We therefore aimed to investigate older adults' implicit sentence processing abilities using ERPs and syntactic comprehension priming, an implicit measure that taps sensitivity to syntactic manipulations. ERPs are neural responses tied to specific sensory or cognitive events, recorded with electroencephalography (EEG), the measurement of electrical activity on the scalp using electrodes (Luck 2014). Language-related ERPs can be recorded in response to semantic or syntactic violations, auditory deviance, or priming (among many other applications), often as increases or decreases in amplitude during a specific time window (called *components*; see Kaan 2007, for an overview). Given the millisecond temporal resolution with which ERPs are measured, the technique is highly suitable for investigating language processing. Whether, and to what extent, older adults' ERP patterns differ from those of younger adults in response to syntactic priming tasks has, to our knowledge, not yet been explored. The relationship between Working Memory and Processing Speed and older adults' syntactic priming are also still unclear, as are the mechanisms underlying syntactic priming effects in general. This study sought to elucidate whether older adults' implicit syntactic processing remains intact, and to what extent Working Memory and Processing Speed contribute to potential age-related syntax processing changes.

1.1 Cognitive aging and sentence comprehension

Language comprehension is intricately tied to cognitive skills, such as WM (Just and Carpenter 1992) and Processing Speed (Salthouse 1996), and past authors have cited these factors as reasons for apparent age-related declines in sentence comprehension. In their seminal paper, Just and Carpenter (1992) directly connected the size of a speaker's WM span to their ability to comprehend longer, more complex sentences. This *capacity-based theory* of comprehension is one of several processing models emphasizing the importance of WM to comprehension (MacDonald and Christiansen 2002; Waters and Caplan 1996).

Before discussing cognitive changes with greater age, however, it is important to emphasize that studies of cognitive aging have used a wide variety of age ranges in their samples. Some of the studies we cite below, for example, have variably defined *younger* as those aged 18-26 (Norman, Kemper, and Kynette 1992), 18-23 (Hardy, Messenger, and Maylor 2017), or a group with a mean age of 19 (Poulisse, Wheeldon, and Segaert 2019). *Older*, conversely, has been defined as including those aged 60-92 (Norman, Kemper, and Kynette 1992), 69-80 (Hardy, Messenger, and Maylor 2017), or a group with a mean age of 71 (Poulisse, Wheeldon, and Segaert 2019). A possible solution to these discrepancies would be to use age-continuous samples, which can provide a more linear, continuous depiction of age-related changes (e.g., Payne et al. 2014). However, these studies may be research-intensive and more costly to conduct. In short, there is no *standard* for what defines a younger or an older adult in cognitive and linguistic research, and various studies may include slightly (or significantly) different age ranges in their samples.

Putting discrepancies in the exact age ranges included in studies aside for now, older adults generally show declines on explicit, declarative memory measures such as span tasks (Bopp and Verhaeghen 2005; Hoyer and Verhaeghen 2006); older groups should, following capacity-based theories, show reduced language comprehension performance as well. Indeed, Norman, Kemper, and Kynette (1992) showed lower scores on comprehension questions for paragraph reading in older compared to younger adults, as well as lower WM spans. An exacerbated decline of both WM capacity and reading comprehension was moreover found in Norman et al.'s oldest participants, those aged over 75. A large-sample meta-analysis by Daneman and Merikle (1996) reinforced the view that declining WM can be directly tied to declining comprehension. Taking data from over 6 000 participants together, these authors suggest sentence comprehension correlates most strongly with WM tasks requiring concurrent processing and storage of information, such as the Daneman and Carpenter (1980) Reading Span Task.

Apart from WM, declining speed of processing has been cited as an important reason for older adults' lower performance on linguistic tasks. Salthouse 1996 claimed the declining speed at which older adults process information results in much of this information being lost when it needs to be retrieved. Activation of these cues, Salthouse (1996) proposes, declines faster in older compared to younger adults. Additionally, older adults spend disproportionate amounts of time on early stages of processing, such as encoding in WM, leaving to little time for later stages such as retrieval. This results in inefficient and qualitatively impaired processing. Linguistic evidence for the Salthouse (1996) account is provided by Grossman et al. (2002), who studied a group of Parkinson's Disease patients and found that longer processing speeds were associated with reduced accuracy on sentence comprehension queries. Additionally, studies routinely find slower overall reading speeds in older compared to younger adults (Hartley et al. 1994; Stine-Morrow, Loveless, and Soederberg 1996; Brysbaert 2019; van Boxtel and Lawyer 2023; among many others).

Finally, a recent investigation by Poulisse, Wheeldon, and Segaert (2019) dismissed WM grounds as the basis for syntactic comprehension issues in older adults, claiming sentence processing declines with aging independently of individual difference measures.

In their experiment, Poulisse, Wheeldon, and Segaert (2019) presented participants with short, two-word phrases to minimize the effect of WM demands. Nevertheless, older adults were less accurate and slower than the younger group in detecting agreement errors in these phrases. When phrases were substituted with pseudo-words, older adults' accuracy declined even further, also suggesting that an absence of semantic content in sentences has a stronger effect in older groups.

Despite this large body of research, there has been a small undercurrent of literature critiquing the dominant belief that cognitive skills decline with age for decades. Schaie (1974) already lamented the dominant trend that "intelligence" declines with age (cf. Horn and Donaldson 1976). More recently, Ramscar et al. (2014)'s opposition to what they term the "myth" of cognitive decline centers around the frequently observed patterns of reduced performance of older adults on psychometric tests, which Ramscar et al. suggest is a result of the larger semantic memory and linguistic experience associated with age, rather than cognitive deficiency. Indeed, a growing body of research suggest older adults maintain intact syntactic comprehension abilities compared to younger groups, and even outperform them. For instance, Hardy, Messenger, and Maylor (2017) tested older and younger adults' sensitivity to syntactic priming, where syntactic structures remain activated or are learned during processing, resulting in an increased tendency to use the same structure in a following experimental trial. Hardy et al. found both age groups were comparably sensitive to syntactic priming, supporting the notion that older adults' sensitivity to syntax does not decline. Additionally, older groups generally score significantly higher than younger adults on measures of vocabulary size (Harada, Love, and Triebel 2013; Verhaeghen 2003), which in turn may positively affect their linguistic skills (cf. Ramscar et al. 2014).

Other variables, including socio-economic status, education, language expertise and experience, and lifestyle patterns, may also be as predictive of, if not more predictive than, chronological age when studying older adults' language and cognition. The importance of socio-economic status and language has been emphasized in numerous studies, which generally show those with higher positions on the socio-economic scale outperforming those with a lower socio-economic status on linguistic and cognitive tasks (e.g., Pace et al. 2017; Warren-Leubecker and Carter 1988). Similarly, those with lower levels of formal education generally perform less well on tests of language comprehension (e.g., Cohen 1979; Im Craik and Byrd 1982), and general indices of health and wellbeing appear highly predictive of performance on cognitive tests (Alwin and Hofer 2011). The effects of age on cognition and language may therefore be characterized more accurately as the combined effects of these and other demographic variables.

Turning back to sentence processing, we further suggest the dissociation between impaired and intact sentence processing in older adults is largely the result of declarative task demands. Declarative memory, which refers to the conscious, explicit extraction of encoded material from mental storage (see Ergo, Loof, and Verguts 2020, for a discussion), declines significantly with age (e.g., Al Abed et al. 2020; Hoyer and Verhaeghen 2006; Reifegerste et al. 2021). Nevertheless, the majority of linguistic tasks examining sentence comprehension have relied on declarative demands. Paragraph comprehension (used by Norman, Kemper, and Kynette 1992, and comprising most of the studies analyzed by Daneman and Merikle 1996) relies on participants searching through memory to find encoded information. Grossman et al. (2002)'s study on Processing Speed in Parkinson's again used sentence comprehension queries. And even Poulisse, Wheeldon, and Segaert (2019) explicitly queried agreement error detection.

We suggest that these impairments are the results of declining declarative memory abilities rather than deficient sentence processing or sensitivity to grammatical structures. The exploratory syntactic priming studies in language production mentioned above support this notion, and suggest syntactic priming may be used as a sensitive implicit measure of sentence comprehension ability, something the current study aimed to explore using a similarly sensitive method for tapping unconscious processing that does not require an explicit response: Event-Related Potentials. Below, we set out how implicit, non-declarative measures are an essential tool for investigating older adults' language, and how syntactic priming and ERPs may combine to form such a tool.

1.2 Syntactic priming in older adults

To our knowledge, virtually all priming studies with older adults or other populations with memory difficulties have focused on language *production* (Hardy, Messenger, and Maylor 2017; Hardy, Segaert, and Wheeldon 2020; Hardy, Wheeldon, and Segaert 2020; Heyselaar et al. 2017), while priming in *comprehension* would address older adults' language processing from a different perspective. Syntactic comprehension priming occurs when the reading of a syntactic structure facilitates consequent reading of that structure (Bock 1986; Tooley and Traxler 2010). Unlike syntactic priming in production (where primed structures are used more frequently than unprimed structures), comprehension priming has proven to be elusive, and is frequently absent without lexical overlap between primes and targets (Tooley, Pickering, and Traxler 2019). Nevertheless, some studies have demonstrated that syntactic priming in comprehension can be recorded through eye-tracking (Thothathiri and Snedeker 2008), ERPs (Ledoux, Traxler, and Swaab 2007), or self-paced reading (van Boxtel and Lawyer 2023). Given the elusiveness of priming effects in comprehension, the use of highly sensitive methods such as ERPs and other types of brain imaging, which do not require explicit, declarative responses, has great potential in this field.

Ledoux, Traxler, and Swaab 2007 elicited syntactic comprehension priming in an ERP paradigm using temporary ambiguities in reduced relative sentences, such as "The parents worried by the teenager decided to talk to him". These structures involve a temporary ambiguity before the word "by", as the first verb may be interpreted as a matrix verb (where, in the above example, the parents caused someone to worry) or as a past participle. Disambiguation effects, observable as an increase in P600 amplitude at the disambiguating word "by", show readers commit to interpreting the sentence in favor of a relative clause interpretation (Mecklinger et al. 1995), and syntactic priming may cause attenuations of this disambiguation effect (Tooley, Traxler, and Swaab 2009; van Boxtel and Lawyer 2023). Ledoux, Traxler, and Swaab 2007 found reduced P600 amplitudes in primed compared to unprimed reduced relatives, and suggested facilitated processing of primed structures reduced unexpected ambiguity effects. Ledoux et al. thus created an innovative paradigm to test implicit sensitivity to linguistic adaptation (for a partial replication, see Tooley et al. 2014).

Studies of syntactic priming in older adults have nevertheless focused almost exclusively on priming in production, which makes recording concurrent ERPs methodologically challenging. Hardy, Messenger, and Maylor 2017 conducted a scripted dialogue task with participants, aiming to elicit passive-active priming. Older adults were significantly more likely to use passives when primed with a passive compared to an active sentence, and even more likely to show priming when lexical overlap existed between prime and target. This effect is known as the *lexical boost*, and syntactic priming in comprehension seems more dependent on the boost than in production (Traxler 2008). Priming in the absence of lexical overlap is also known as *abstract* syntactic priming. Hardy and colleagues replicated significant abstract priming and lexical boost effects in several further studies with older adults (Hardy, Segaert, and Wheeldon 2020; Hardy, Wheeldon, and Segaert 2020; Heyselaar, Wheeldon, and Segaert 2021).

Older adults' priming data have an important role in determining the causes of syntactic priming. While early priming accounts focused exclusively on activational spread as the underlying mechanism for syntactic priming (Pickering and Branigan 1998), non-declarative causes such as implicit learning mechanisms are now more widely supported by the available evidence (Chang 2008; Chang, Janciauskas, and Fitz 2012). Nevertheless, the long-lasting nature of abstract syntactic priming compared to the short-livedness of the lexical boost (Hartsuiker et al. 2008) led to dual-mechanism accounts of priming, where lexical effects rely on declarative mechanisms, and abstract priming is rooted in implicit, non-declarative abilities (e.g., Tooley and Traxler 2010; Traxler, Tooley, and Pickering 2014). The available evidence from older adults, whose declarative memory abilities are subject to decline, has further suggested non-declarative, implicit skills are the more likely underlying mechanism for syntactic priming and possibly for the lexical boost (Heyselaar et al., 2020). If this is indeed the case, neurophysiological data should provide an additional source of evidence supporting the idea that older adults continue to be sensitive to repetitions in syntactic and lexical structure. Exploring this in detail will help disentangle the degree to which behavioral changes in older adults' responses are driven by declines in comprehension abilities, or whether these changes are only observed in tasks demanding the use of declarative memory.

1.3 The Present Study

In this study, we used Event-Related Potentials to investigate syntactic comprehension priming in groups of older and younger adults. Specifically, we aimed to determine whether older adults showed facilitated reading of reduced relative clause sentences and attenuations of associated ERPs (after Ledoux, Traxler, and Swaab 2007, who explored this technique with younger adults). As summarized above, effects of disambiguation in reduced relatives can be modulated by syntactic priming, and so we expected faster reading of disambiguating regions in primed compared to unprimed trials, and faster reading still in boosted compared to primed trials. Ambiguity-related P600s were hypothesised to show attentuations in primed trials, and negativity related to lexical effects should show reductions in trials with repeated lexical items. Previous literature suggests differences by age group should be minor (e.g., Hardy, Messenger, and Maylor 2017; Hardy, Segaert, and Wheeldon 2020), though potentially more likely on measures of the lexical boost as this effect is often considered to rely on explicit factors (e.g., Traxler, Tooley, and Pickering 2014; Hardy, Messenger, and Maylor 2017).

The remainder of this paper is structured as follows: first, we discuss the methodology of our self-paced reading and ERP paradigm, as well as demographics of the older and younger adults who took part (section 2). Sections 2.3 and 2.4 describe the statistical analyses and ERP recording parameters used in the present study, including statistical modelling and ERP artefact detection strategies. Section 3 lists our results, beginning with behavioral responses before discussing regions of interest for the ERP analysis and listing corresponding findings. Finally, we discuss these findings in Section 4, our discussion.

2 Methods

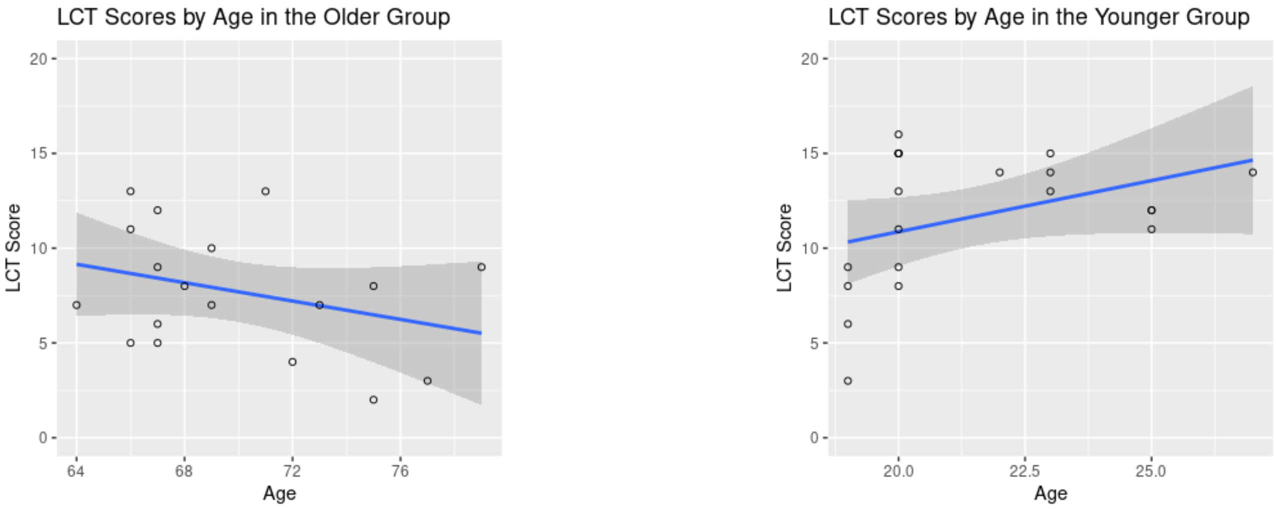
2.1 Participants

Older (n=18; M_{Age}=69.6; [64,79]) and Younger (n=20; M_{Age}=21.4; [19;27]) participants took part in this experiment and were paid for their participation. All participants confirmed they were dominant speakers of English, had normal or corrected-to-normal vision, and no history of neurological or cognitive impairments. Participants who required eyeglasses wore these during the study, though any hearing aids were removed prior to the ERP phase of the study. No stimuli or instructions were presented auditorily during any part of the study. Participants provided informed consent before taking part. Table 1 displays a full summary of participant demographics. Biodata measures were compared between groups using independent-samples t-tests and Bayesian regression models using the *brms* packages in R 1.4.1717 (Bürkner 2017; R Core Team, 2020). Bayes' Factors smaller than 1 indicate evidence for the null hypothesis – in our case, that no by-group differences existed in biodata measures (Lee and Wagenmakers 2014).

Table 1: Overview of participant demographics. Education levels were measured along the International Standard Classification of Education (Statistics 2012), ranging from 0 (less than primary education) to 8 (doctoral or equivalent). Both education levels and years in education were self-reported. *LCT* denotes Letter Comparison Test, while *RST* stands for Reading Span Task.

Group	*Age*	*Gender*	*Years in Education*	*Education Level*	*LCT Score*	*RST Score*
Older	M=69.6; SD=4.01; [64,79]	13 F, 5 M	M=15.68; SD=4.12; [9,25]	*Mode*=5	M=7.22; SD=3.27; [3.13]	M=13.5; SD=6.02; [2.5,26.5]
Younger	M=21.4; SD=2.28; [19,27]	18 F, 2 M	M=15.49; SD=2.45; [8,20]	*Mode*=3	M=11.65; SD=3.50; [3,16]	M=17.57; SD=6.12; [7,28]

Older and younger participants had spent a similar number of years in formal education (t(26.7)=-.146, p=.885; BF=2.84 (ambivalent)), and both groups showed roughly equal levels of education (t(32.6)=-1.146, p=.26; BF=2.80 (ambivalent)). Older participants scored lower on our measure of Processing Speed (the Letter Comparison Test or LCT, see section 2.2.1 below) than Younger adults (t(35.9)=3.577, p=.001; BF>100). Older adults further exhibited smaller WM spans (as measured by the Reading Span Task, see Section 2.2.2 below) than the Younger group (t(36)=2.300, p=.03; BF>100). However, while Reading Span Task scores showed an expected distribution where age was associated with lower scores in both groups, LCT scores showed a different pattern. As visualised in Figure 1, LCT scores declined with age in the Older group, but were positively related to age in the Younger group, potentially due to a subset of low-scoring younger participants (see the left pane of Figure 1). A cross-correlation table of all predictors is presented in Figure 2, showing strong expected correlations between our two measures of education, expected negative correlations between age and pre-test scores, and weak correlations between our other predictors.


LCT Scores by Age in the Older Group

LCT Scores by Age in the Younger Group

(a)

(b)

Figure 1: Plots of scores on the Letter Comparison Test by numerical age, faceted by Age Group. LCT scores were negatively related to age in the Older group, where those with lower LCT scores were older than those with higher scores, but not in the Younger group, where the opposite pattern was observed.

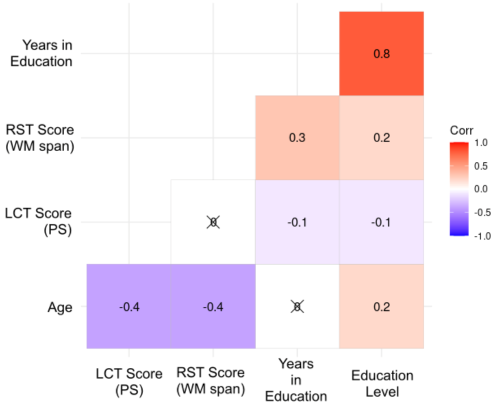


Figure 2: Cross-correlation matrix of predictor variables. This matrix shows expected high correlations between Years in Education and Education level, and no strong correlations between other predictors.

2.2 Materials

2.2.1 Letter Comparison Test

We used the Letter Comparison Test (Salthouse and Babcock 1991; Salthouse 1991) to assess Processing Speed. In the LCT, participants are asked to judge whether two character strings presented on screen are identical or different. The test times out after thirty seconds, and participants' score is calculated as the number of correct trials within this period. We used the LCT rather than the popular Digit Symbol test of the Wechsler Adult Intelligence Scale (Drozdick et al. 2018; Wechsler 1955) as the LCT involves little to no memory or processing demand and can therefore be considered a more direct measure of Processing Speed itself. The LCT for this study comprised 48 string pairs of 3, 6, or 12 letters each (equally subdivided), half of which were identical and half were different. Letter strings were checked for similarities to English words, and five practise trials preceded the experimental phase.

2.2.2 Reading Span Task

To measure WM, we used Daneman and Carpenter's (Daneman and Carpenter 1980) Reading Span Task (hereafter RST): participants were asked to rate sets of sentences for appropriateness, as well as to remember the final word of each sentence. For instance, for the item "Filter coffee is the superior drink", participants should respond "appropriate" and remember "drink". Similarly, for "Dusty library books were the man's house", the correct response was "inappropriate" and "house". After the sentence-by-sentence presentation of each set, participants were prompted to type the final words they had recalled into a box on screen. Sentences were presented in increasingly longer sets, ranging from three to eight sentences. Sentences had an average length of 6.97 words (SD=1.44) and comprised simple grammar without complex or compound structures. One practise set of two sentences preceded the experimental phase. Participants were encouraged to recall words in the correct order, and one point was assigned for each word recalled in its correct place – half points were given to words recalled in the correct set, but the incorrect order (following Conway et al. 2005). The sum of all points across sets was used as a participant's WM span.

2.2.3 Main Study

Items for the main experiment were sourced from Tooley, Traxler, and Swaab (2009), Manouilidou et al. (2009), and Traxler (2008). 90 trial sequences were constructed in total, equally subdivided into Unprimed, Primed, and Boosted conditions (30 trials per condition). Each trial consisted of one Prime, one Target, and at least two (maximum 4) Filler sentences. There was no syntactic and no lexical overlap between Prime and Target in the Unprimed condition; the Primed condition involved reduced relative structures as both Primes and Targets, but in the absence of lexical overlap; and in the Boosted condition, Primes and Targets shared a reduced relative structure as well as a main verb. EEG responses (see Section 2.4 below) were time-locked to each word in Primes and Targets.

Filler items comprised sentences with complex syntactic structures, but excluded reduced relative clauses and lexical repetition (except where intended; see below). At least two Fillers intervened between Prime and Target; lists of all critical and filler trials appear in our Supplementary Materials (van Boxtel 2021). Trials were randomly assigned to one of five blocks of 18 trials each. One block thus showed 90 sentences on average, depending on the amount of intervening fillers. This meant each participant read an average of 450 sentences. Items ranged from 7 to 14 words, with an average length of 9.66 words, and there were no significant differences between the lengths of Prime and Target items ($t(169)=-.77$, $p>.05$).

Additionally, we aimed to investigate lexis-only overlap by introducing a Lexical Control Condition (hereafter LCC) in second filler items – 30 second fillers in Unprimed trials included either the same verb as the Prime, or a different verb matched in position to repeated verbs. The LCC manipulation left Prime—Target sequences unaffected, and allowed us to investigate lexical effects in the same trials as syntactic priming without compromising the elicitation of the priming effect. EEG responses were also obtained in the LCC. Figure 3 includes a full example set of a trial sequence including example sentences.

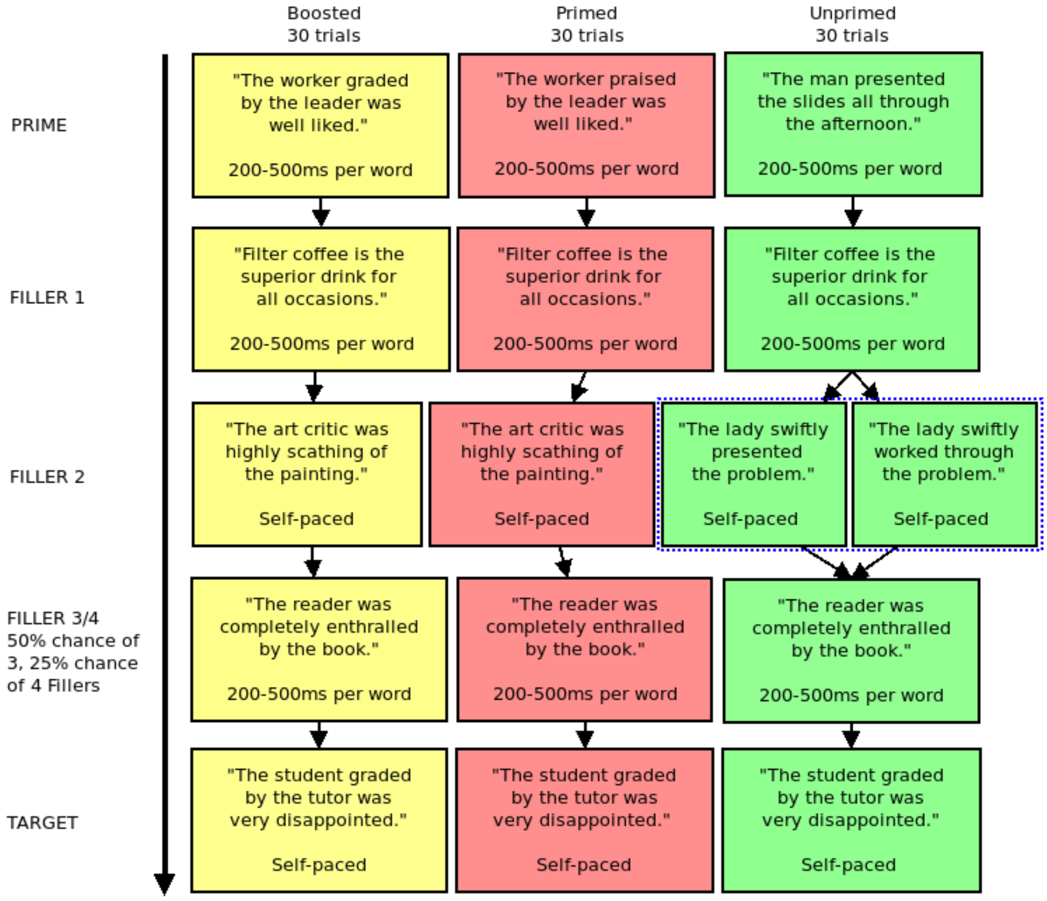


Figure 3: Example of experimental trial sequence. Each trial progresses from the top of the figure (Prime) to the bottom (Target). There was a 50% chance of Filler 3 being presented, and of those trials there was an additional 25% chance of Filler 4 being presented. Each condition is marked with its own color (yellow=Boosted; red=Primed; green=Unprimed) and the Lexical Control Condition is marked in a dashed block. There was a 50% chance of comprehension questions appearing after any Prime, Filler, or Target.

2.3 Procedure

Participants completed the study in a dimly lit room on a 21.5-inch Iiyama B2283HS monitor, and responded using a wired keyboard. Both pre-tests as well as the main study were presented using OpenSesame 3.3 (Mathôt, Schreij, and Theeuwes 2012) running on Ubuntu 20.04. The LCT and RST were completed before the main study. The main experiment took participants between 50 and 70 minutes. Participants were offered the opportunity for a break between all blocks of the main experiment. Block order was fully randomized across participants, as was the order of trials within blocks.

Primes and all filler sentences except Second Fillers (which were used for lexical repetition control) were externally paced at random durations between 200 and 500 ms to avoid anticipatory stimulus-preceding negativity (Brunia, Van Boxtel, and Böcker 2011). Our presentation rates therefore mirrored those of Ledoux, Traxler, and Swaab (2007). Participants paced through Targets and Second Fillers by pressing the space bar to advance word-by-word through the sentence. While motor potentials related to self-paced reading may show on ERP signals (e.g., Falkenstein, Hoormann, and Hohnsbein 1999; Touzalin-Chretien, Ehrler, and Dufour 2010), self-paced reading methods have been successfully combined with ERPs in past studies (e.g., Ditman, Holcomb, and Kuperberg 2007). Moreover, given that the same button press is required on all trials regardless of priming condition, motor potential interference would not have affected differences between conditions. Self-paced items were marked by the presentation of a yellow block surrounding the fixation cross, which participants were trained to recognize in the practise phase: seven practise trials, two of which were self-paced, preceded the experimental phase. There was a 50% chance of comprehension questions appearing after any sentence, which queried an action statement from that sentence. Questions were randomly interspersed throughout items and trials to prevent participants from detecting the structure of Prime-Target sequences. Half of all questions required a positive, and half a negative response.

2.3.1 Behavioral Analysis

Data analysis was conducted in R (R Core Team 2013) using the *lme4* package for linear mixed modelling (Bates et al. 2015), *sjPlot* for mixed model plotting (Lüdecke 2015), *EMAtools* for generation of effect sizes (Kleiman 2017), *brms* for Bayesian mixed modelling (Bürkner 2017) and *bridgesampling* for calculation of inverse Bayes Factors (Gronau, Singmann, and Wagenmakers 2017).

For analysis of reading times, we defined four temporal Regions of Interest (ROIs). In Targets, the disambiguating ROI (hereafter *By ROI*) ranged from "by" up to and including the following noun ("by the teenager" in (1) below). We further defined a two-word *Spillover ROI* following the By-ROI ("decided to" in the below example (1)). For the LCC in Second Fillers, we examined reading times on the main verb (hereafter the *Verb ROI*; "presented" in (2)), where ERP triggers were also sent, and a two-word Spillover ROI similar to that in Target sentences ("the quarterly" in (2)). Event-Related Potentials were time-locked to the onset of "by", the preceding verb, and the following noun in Targets, as well as on verbs in Second Fillers. The verb immediately preceding "by" was investigated as this is where lexical repetition from Prime sentences occurred in Boosted trials; the noun following "by" was additionally investigated as effects of syntactic disambiguation may have carried over from "by" to this noun (consider, in relation to (1), "The parents worried by the door, anticipating the scary visitor.")

(1) (*Target*) The parents worried // by the teenager // decided to // talk to him.
(2) (*Second Filler*) The CEO proudly // presented // the quarterly // figures with glee.

Behavioral Linear Mixed Models (LMMs) were constructed for reading times in each ROI, including random effects for Subject and Trial, and fixed effects for Condition*Age Group, Condition*RST Score, and Condition*LCT Score. Condition parameters were contrast coded such that models contrasted Unprimed vs. Primed trials (to measure abstract priming) and Primed vs. Boosted trials (targeting the lexical boost). Neither self-reported education measure approached significance in any model or ROI, and these are therefore not further reported. Prior to modelling, reading times were residualized by character count: Residualized reading times (RRTs) were calculated as the division of an ROI's reading time by the ROI's length in characters. RRTs were then log-transformed to improve normality prior to analysis.

We followed up on our main models using Bayesian Linear Mixed Models, which express the likelihood of null hypotheses with greater confidence than traditional statistical techniques. Bayesian reading time models were constructed using weakly informative ex-Gaussian prior distributions, which are appropriate for RT data (Matzke and Wagenmakers 2009), while EEG models were fitted using Gaussian (normal) prior distributions. One set of models included main parameters of age group and condition (null models) while the other set included age group by condition interactions (full models). Comparing these models yielded inverse Bayes' Factors (BFs), which offer the likelihood of the null or full hypothesis being correct (Lee and Wagenmakers 2014). BFs of <1 offer evidence for the null hypothesis (with smaller values offering stronger evidence), while large BFs of at least 1 speak in favor of the full hypothesis. For the full code used for our Bayesian analysis, please refer to our Supplementary Materials (van Boxtel and Lawyer 2023). See further Wagenmakers (2007) for procedures on confirming null results with Bayesian models.

2.4 EEG Recording

EEG signals were obtained using a BioSemi system with 64 Ag-AgCl scalp electrodes (BioSemi Instrumentation, Amsterdam, NL), which were placed in accordance with the extended 10-20 positioning system. Ocular movements were recorded using three electrodes placed above, below, and to the side of the right eye. EEG data was sampled at 512Hz. ERP triggers were coded in the *pyserial* toolbox (Liechti 2016) in OpenSesame 3.0 and time-locked to the windows described in section 2.3.1 above.

EEG recordings, referenced the average of both mastoids, were analysed using EEGlab v.2021.1 (Delorme and Makeig 2004) and ERPlab 8.40 Lopez-Calderon and Luck 2014), running in Matlab R2021b (MATLAB 2021). All data were downsampled to a rate of 256Hz for analysis. Datasets were filtered with a high-pass IIR Butterworth filter of .01 and low pass of 30Hz. Blink components were automatically flagged after Independent Component Analysis using the *iclabel* plugin (Pion-Tonachini, Kreutz-Delgado, and Makeig 2019), but manually confirmed in each dataset. Electrodes with significant channel noise were interpolated spherically, and an overview of all interpolated electrodes can be found in the

Supplementary Materials at https://osf.io/3yrnv. ERPs were computed in epochs ranging from 200 to 1000 ms around the stimulus, and two rounds of ocular artefact detection were conducted. The first round detected ocular artefacts in external eye channels using a 60 V moving window peak to peak threshold, and a second round employed the same method on al scalp channels with a threshold of 120 V. The average proportion of rejected trials across participants and groups was 14.7%. The highest proportion of rejections for any participant was 25.8% of trials – artefact rejection further led to the elimination of one Younger participant's data whose rejection rate was 44.2%. Our supplementary materials contain ERP processing notes including rejection details.

3 Results

For full model output tables, please refer to Appendix A.

3.1 Behavioral – Reading Times

3.1.1 By-ROI

Table 3 (Appendix A) details model parameters in Target regions. Effects of Priming Condition were not evident in the By-ROI, neither for abstract priming (t(99.2)=-.830, p>.05, d=-.167) or for the lexical boost (t(98.3)=-.231, p>.05, d=-.047). While older adults read more slowly across conditions (t(3012)=-22.93, p<.001, d=-.836), there were no group differences by abstract priming condition (t(3004)=.981, p>.05, d=.036) or by lexical boost condition (t(3004)=.492, p>.05, d=.018). This was confirmed in our Bayesian models (BF=.0013). Both age groups, therefore, showed no effects of syntactic priming conditions in this ROI.

Pre-tests significantly affected reading times in the By-ROI, such that higher RST scores were associated with faster reading across conditions (t(2981)=-4.902, p<.001, d=-.180), while high scores on the LCT unexpectedly led to slower reading times (t(2988)= 11.983, p<.001, d=.438). While LCT scores did not interact with either priming contrast (Abstract t(3003)=-.015, p>.05, d=-.000; Boost t(3003)=-.211, p>.05, d=-.008), there was a weak yet consistent interaction between RST score and abstract priming (t(3004)=-2.193, p=.028, d=-.080), such that greater facilitating effects of RST score were apparent in Primed and Boosted compared to the Unprimed condition.

3.1.2 Spillover ROI

The Target Spillover ROI was more sensitive at capturing effects of priming than the preceding region. Clear abstract priming (t(93.5)=-2.797, p<.01, d=.579) and lexical boost effects (t(93.2)=3.803, p<.001, d=.788) were found.

Figure 4 illustrates this effect, which comprised a step-wise facilitation where Boosted trials were read faster than Primed trials, which in turn were read faster than Unprimed trials. These patterns were in line with expectations of syntactic priming in comprehension. Crucially, there was no interaction between age group and abstract priming (t(3017)=.666, p>.05, d=.024) or lexical boost (t(3017)=-.986, p>.05, d=-.036), indicating that both age groups experienced similar priming effects (confirmed in Bayesian models, BF=.0027).

As in the By-ROI, reading times across conditions were slower in the Older compared to the Younger group (*t*(3012)=-22.932, *p*<.001, *d*=-.836) and were similarly facilitated by high RST scores (*t*(2981)=-4.902, *p*<.001, *d*=.180). Contrary to expectations, reading times increased as LCT scores became higher (*t*(2988)=11.983, *p*<.001, *d*=.438), an effect visualized by group and priming condition in Figure 5.

There were no interactions of pre-tests by either priming condition (ps>.05), except a small yet significant one of LCT score by abstract priming (*t*(3004)=-2.193, *p*<.05, *d*=.080), such that somewhat greater LCT-related facilitation was observed in Primed and Boosted compared to Unprimed Targets. To investigate this further, we additionally entered a three-way Condition*Group*LCT interaction into the Spillover ROI model, however this did not reach significance (Abstract*Group*LCT: *t*(3014)=1.631, *p*>.05, *d*=.059; Boost*Group*LCT: *t*(3014)=1.408, *p*>.05, *d*=.051) and these terms are therefore not further reported here.

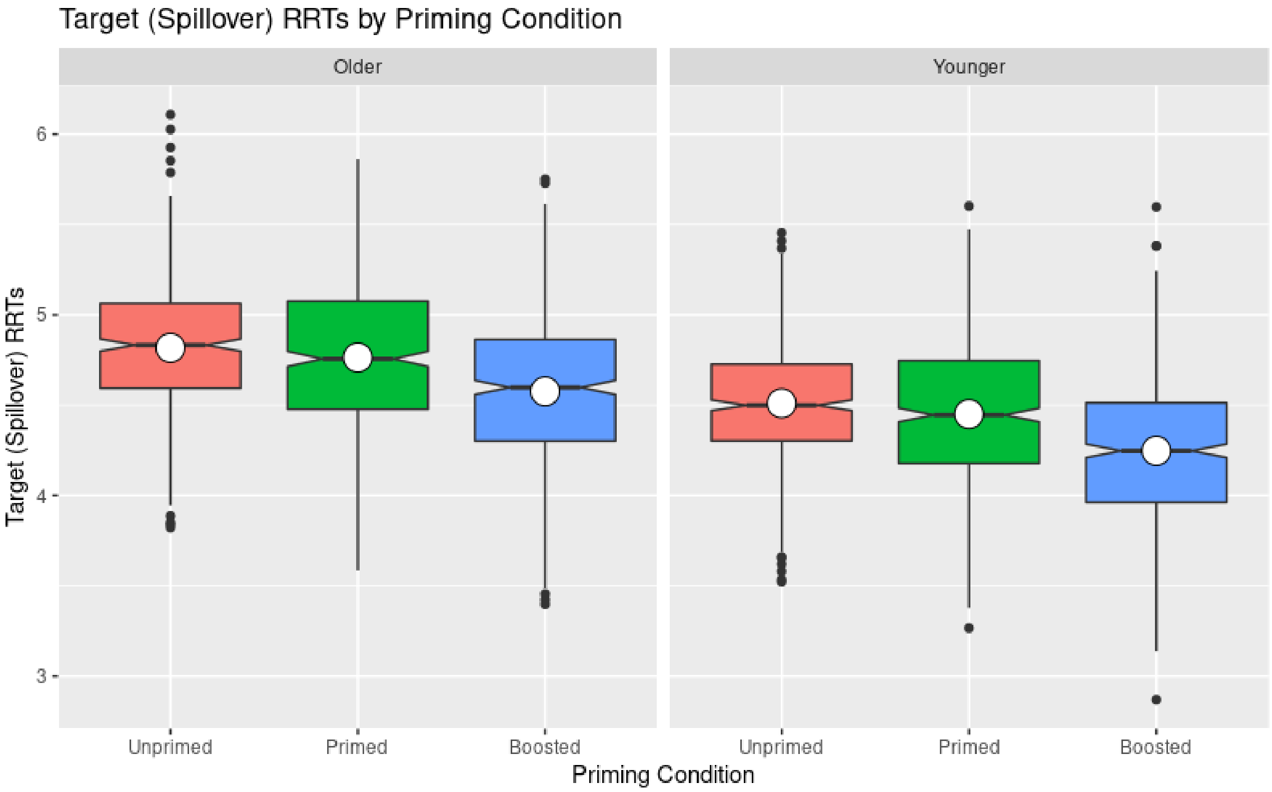


Figure 4: Plot of residualized reading times in the Target (Spillover) ROI by Priming Condition and Group, showing a step-wise facilitation from Unprimed to Primed to Boosted in both groups, and generally slower reading times in the Older group.

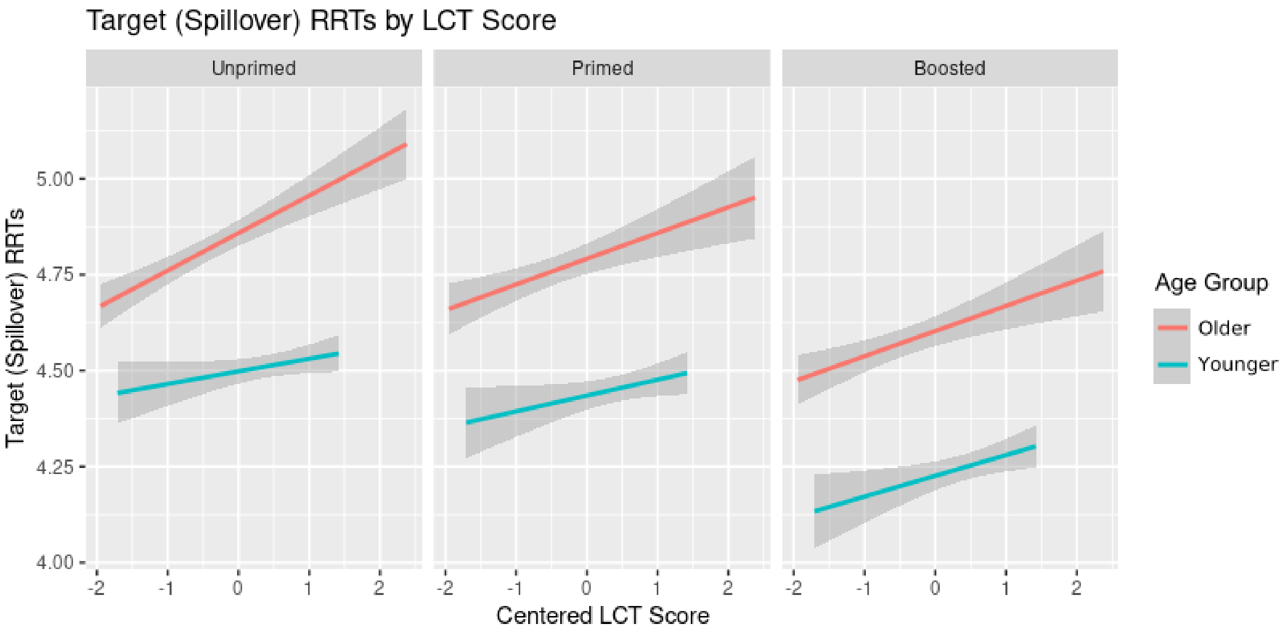


Figure 5: Residualized reading times in the Target (Spillover) ROI by centered LCT Score, Priming Condition, and Age Group.

3.1.3 LCC ROIs

Similar to Target ROIs, effects of the LCC were more evident in the Spillover region (see Table 4 for details). The Verb ROI did not return any significant conditional parameters (all *p*s>.05), suggesting this ROI was not sensitive to repetition-related facilitation. No main effects of lexical repetition were evident in the Spillover ROI, either (p>.05), however the inclusion of an Age Group by Repetition interaction term revealed this lack of main effect was due to differing responses by group.

Specifically, while younger adults were facilitated by lexical repetition, the older group showed no such facilitation, an effect visualized in Figure 6 (*t*(1490)=2.365, *p*<.05, *d*=.122; BF=.2164). Older adults therefore showed facilitated reading times, in line with the Younger group, when syntactic and lexical overlap were present, but they did not show facilitation when only verbal overlap was manipulated.

Again, the LCC Spillover ROI showed slower reading times across conditions for Older compared to Younger groups (*t*(1479)=-13.302, *p*<.001, *d*=.687) and both pre-tests affected reading times as in previous ROIs (facilitatory effect of RST: *t*(1413)=-2.777, *p*<.05, *d*=.148; non-facilitatory effect of LCT: *t*(1427)=5.111, *p*<.05, *d*=-.271).

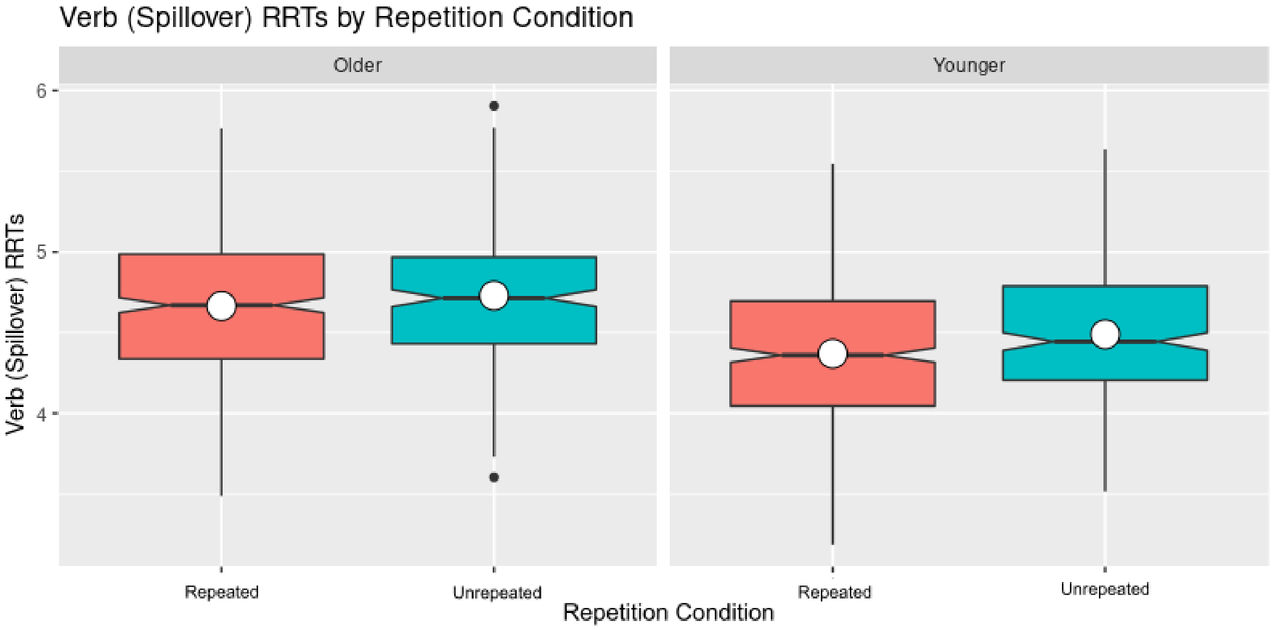


Figure 6: Plot showing residualised reading times in the LCC Spillover ROI by Repetition condition and Age Group. Larger facilitation effects of verb repetition are visible in the Younger compared to the Older Group.

3.2 ERPs

3.2.1 Analysis and Focus

As described in Section 2.3.1, ERP triggers were sent upon presentation of “by” in reduced relative Targets, where a P600 was expected, as well as the preceding verb, which was repeated from Primes in Boosted trials and where we anticipated a lexis-related N400, and the following noun, where both lexical and syntactic effects were investigated. In the LCC, triggers were sent on the repeated or unrepeated verb, again with the expectation of eliciting N400 effects.

Following previous investigations of syntactic priming and ERPs, we anticipated P600s (on “by” and preceding verbs) to take a centro-parietal distribution between 500 and 700 ms post-onset (e.g., Ledoux, Traxler, and Swaab 2007). N400 effects were hypothesized to take a wider distribution, spanning a broad selection of parietal electrodes (e.g., Chen et al. 2013). While effects in this window appeared right-lateralized from visual observation (an uncommon though not unprecedented distribution, see literature from semantic priming, e.g., Curran et al. 1993; Kiefer et al. 1998; Franklin et al. 2007; Frishkoff 2007), a wide parietal selection of electrodes captured effects appropriately. Further, visual inspection showed syntactic effects in frontal rather than parietal sites, and also pointed towards a robust late frontal positivity on the same Target verbs where we originally intended to find N400 effects, observable in broad frontal sites and in both groups. This effect is further illustrated in the scalp plots in Figure 7.

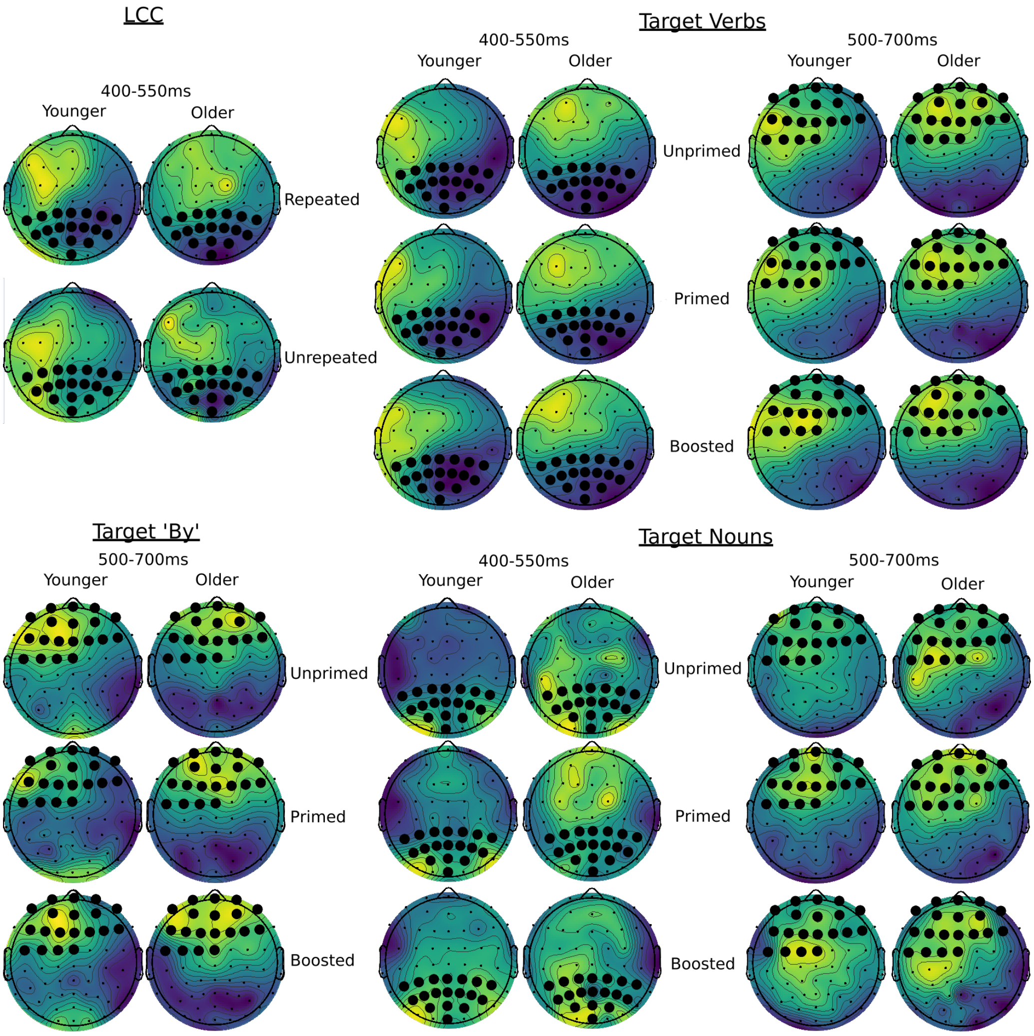


Figure 7: Scalp plots of mean amplitude between latencies included in the analysis. Electrodes included in linear mixed models are highlighted in bold dots.

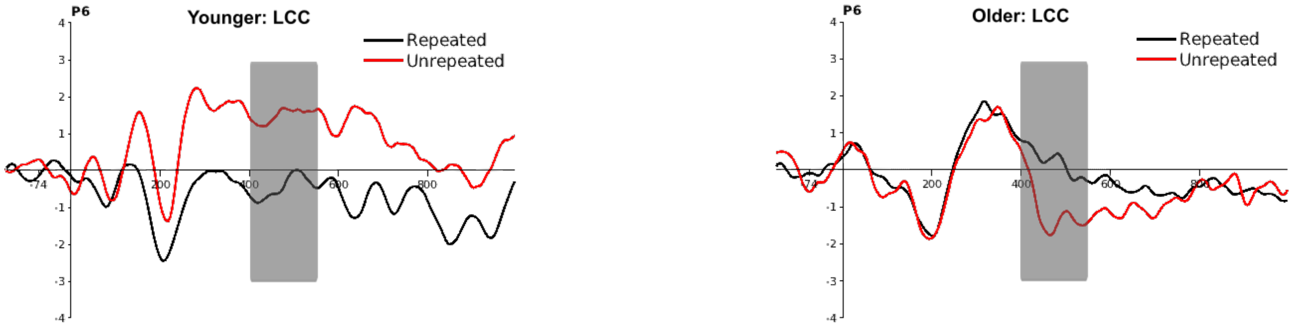
Table 2 provides an overview of the electrodes and time windows pre-defined for the analysis of each effect. Scalp plots of these effects in both groups are provided in Figure 7, while a full overview of included sites and latencies by effect and group can be found in Table 2. Models were constructed predicting mean amplitude in the sites and windows described above, including a random effect for Participant, and fixed effects for conditional parameters and interactions with Age Group.

3.2.2 Lexical effects in the LCC

Robust effects of lexical repetition were found in the 400-550 ms window we defined (see Table 5; $t(1271)=4.900$, $p<.001$, $d=.275$), which differed significantly by group ($t(1270)=-9.581$, $p<.001$, $d=-.538$).

Table 2: Overview of electrode sites and time windows included in analysis for each reported effect of interest (and examples of where these effects were recorded).

	Place of recording	*Region of Interest*	*Window post-onset*
LCC: centro-parietal negativity	Second fillers: matrix verb (*The CEO proudly* ***presented*** *the quarterly figures*)	CP5 CP3 CP1 CPz CP2 CP4 CP6 P5 P3 P1 Pz P2 P4 P6 PO3 Poz PO4 Oz	400-550 ms
Target Verbs: centro-parietal negativity	Targets: first verb (*The parents* ***worried*** *by the teenager decided to talk to him*)		
Target Verbs: frontal positivty	Targets: first verb	FP1 FP2 AFz AF3 AF4 AF7 AF8 Fz F1 F2 F3 F4 F5 F6 FCz FC1 FC3 FC5	500-700 ms
Target "by": frontal positivty	Targets: disambiguating "by" (*The parents worried* **by** *the teenager decided to talk to him*)		
Target Nouns: fronto-central negativity	Targets: second noun (*The parents worried by the* ***teenager*** *decided to talk to him.)*		400-550 ms
Target Nouns: front-left positivity	Targets: second noun	FP1 FP2 AFz AF3 AF4 AF7 AF8 Fz F1 F2 F3 F4 F5 F6 FCz FC1 FC3 FC5	500-700 ms



(a)

(b)

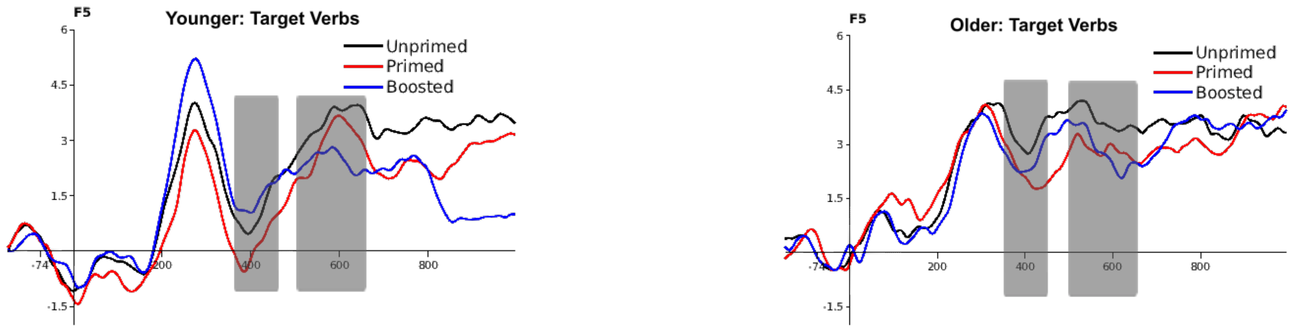
Figure 8: ERP plots of waveforms following LCC verbs at site P6, highlighting the analysed ROI in gray, and showing expected N400 attentuations in the Older (b) but not the Younger (a) group.

Specifically, while Older adults exhibited the expected pattern of attenuated negativity in response to repeated trials, Younger adults showed the opposite pattern (confirmed with Bayesian model comparisons: $BF_{Group*LCC}>1000$). This is further visualised in Figure 8.

3.2.3 Lexical effects on Target Verbs

Effects in the N400 window on Target verbs were in the expected direction: repeated verbs in Boosted trials elicited less negative responses than unrepeated verbs in Primed trials ($t(1270)=-4.037$, $p<.001$, $d=-.227$). Additionally, both groups exhibited a very similar lexical boost effect ($t(1270)=.927$, $p>.05$, $d=.052$), and there was further no main effect of Age Group on amplitudes, either ($t(37)=-1.463$, $p>.05$, $d=-.484$). Bayesian models returned an ambivalent BF=5.917. Table 6 (Appendix A) displays results for the modelling in this ROI.

Additionally, the late frontal positivity on Target Verbs was also modulated by Priming Condition, confirming the presence of a *Verbal* P600. Indeed, amplitudes were attenuated both by abstract priming condition ($t(1957)=5.691$, $p<.001$, $d=.257$) and the lexical boost ($t(1957)=4.773$, $p<.001$, $d=.216$), and showed no significant difference by Age Group ($t(35)=-1.251$, $p>.05$, $d=-.518$) or modulations between Age Group and either condition parameter (both *p*s>.05). Bayesian models not suggestive of group differences ($BF_{abstract}=1.07$; $BF_{boost}=5.514$). Full details of models in this ROI can be found in the lower panel of Table 6 (Appendix A), while an example of the *Verbal* P600 can be seen for each group in Figure 9.



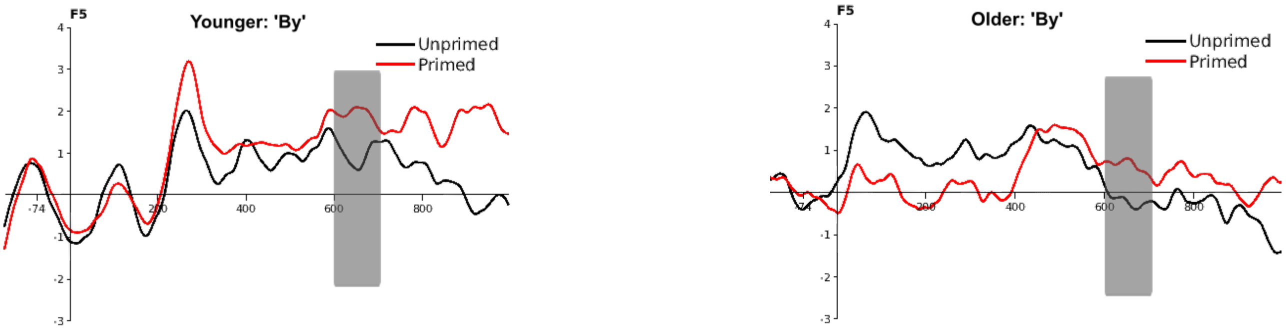
(a)

(b)

Figure 9: ERP plot of responses following Target Verbs, highlighting both the earlier N400 and later P600 response in both groups.

3.2.4 Syntactic effects on "by"

In the P600 window, we found indications for a positive-going waveform at the presentation of "by" in frontal sites. While syntactic P600 effects are traditionally found in centro-parietal sites (see Gouvea et al. 2010, for a discussion), frontal positivities are not without precedent and could be indicative of specific memory-focused processes underlying the effect (Guillem et al. 1995; Leckey and Federmeier 2020). We discuss this distribution in greater detail in our discussion. Disambiguation-related positivity attentuations at "by" in Targets were not as robust as anticipated, with priming effects marginally affecting ERP signals ($t(1262)=-1.961$, $p=.05$, $d=-.110$). Figure 10 shows that this effect took an unanticipated direction, such that both groups showed more positivity in response to Primed compared to Unprimed trials. Older and Younger participants did not show different neural responses in this time window and ROI overall ($t(36)=.502$, $p>.05$, $d=-.226$); however, the Younger group showed a larger effect of Priming Condition ($t(1263)=2.689$, $p<.01$, $d=.151$). Bayesian model comparisons were also suggestive of this difference: $BF_{Group*Condition}=17.640$. See Table 7 for full model reports in this region.



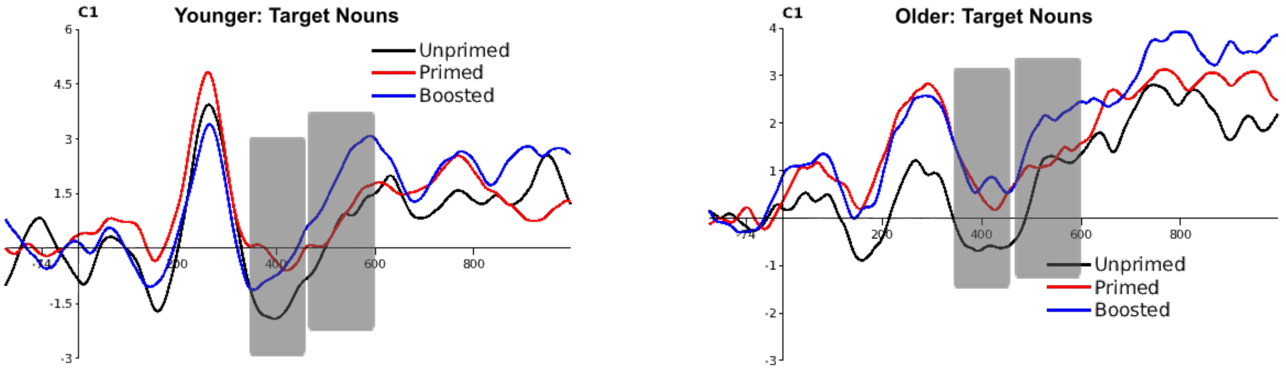
(a)

(b)

Figure 10: ERP plots of responses following “by” in Target, averaged by Younger (a) and Older (b) age groups. Effects of syntactic disambiguation were minor and inconsistent in this ROI: both groups showed indications for effects in the opposite direction of our expectations: more positivity in response to Primed compared to Unprimed trials. However, effects reached significance only in the Younger group.

3.2.5 Effects on Target Nouns

Effects in this ROI were divided into two temporal regions. The theoretically-motivated P600 was analyzed in the 500-700 ms time window, but this effect was preceded by an earlier negative-going effect (see Figure 11). This effect was observed in the 300-550 ms time window, comprising reduced negativity in Primed and Boosted compared to Unprimed trials. The effect was similarly consistent in both groups ($t(1957)=-4.068$, $p<.001$, $d=-.184$; by-group interaction $t(1957)=.221$, $p>.05$, $d=.010$) ,with Bayesian model comparisons yielding more evidence for an absence of group effects: $BF_{Group*Condition}=.602$. Further, no general effects of age group were evident in this ROI ($t(35)=-.212$, $p>.05$, $d=-.072$). Second, the later effect in the 500-700 ms time window was observed where Boosted trials evoked *more* positivity than the other conditions: this was confirmed statistically in both groups ($t(1957)=-2.454$, $p=.01$, $d=-.104$; by-group interaction $t(1957)=.160$, $p>.05$, $d=-.010$), including with Bayesian model comparisons ($BF_{Group*Condition}=.257$). We discuss the unexpected direction of this positive-going effect in the Discussion. Full model summaries on Target Nouns are given in Table 8.



(a) (b)

Figure 11: ERP plots of responses following “by” in Target, averaged by Younger (a) and Older (b) age groups. In the earlier time window, Unprimed trials evoked more negativity than Primed and Boosted trials, while the later time-window showed Boosted trials evoking more positivity than the other two conditions.

4 Discussion

This study reports a syntactic comprehension priming experiment conducted with groups of older and younger adults while EEG recordings and reading times were obtained. Priming was elicited in both the Older and Younger groups, observable as faster reading times in reduced relative sentences primed with a preceding reduced relative, and additional facilitation when sentences were primed with reduced relatives containing the same main verb. Event-Related Potentials further showed priming effects, with (1) robust N400 attentuation on Target Verbs in Primed compared to Unprimed trials; (2) step-wise attentuations of a Verbal P600 when Targets were Primed and Boosted compared to Unprimed; (3) inconsistent effects of syntactic disaabiguation on “by”; (4) robust effects on Target Nouns in the form of early N400 attentuations on Primed and Boosted compared to Unprimed trials, and a later P600 attenuation on Primed and Unprimed compared to Boosted trials. Behavioral performance showed no age-related changes, except on lexis-only priming. However, some indications for underlying age differences were evident from the electrophysioloical data in terms of topography and distribution of activation.

4.1 Age Effects: What Changes and What Doesn’t?

Behaviorally, both age groups experienced abstract syntactic priming (in the absence of lexical overlap) and lexical boost effects (where both syntactic and verbal overlap were included): in both groups, Boosted Targets were read faster than Primed Targets, which were in turn read faster than Unprimed Targets. This reinforces recent evidence suggesting older adults are as susceptible to syntactic priming as younger adults in behavioral responses (Hardy, Messenger, and Maylor 2017; Hardy, Segaert, and Wheeldon 2020; van Boxtel and Lawyer 2023), and contradicts past literature suggesting syntax processing declines with age (e.g., Norman, Kemper, and Kynette 1992; Poulisse, Wheeldon, and Segaert

2019; Zhu, Hou, and Yang 2018). We suggest this dichotomy is due to previous investigations' focus on declarative, explicit measures, while syntactic priming relies on implicit, non-declarative cognitive skills (see further Heyselaar, Wheeldon, and Segaert 2021; van Boxtel and Lawyer 2023). This study therefore makes the case for further investigations into older adults' sentence processing using implicit tasks.

Crucially, our experiment is, to our knowledge, the first to report older adults' sensitivity to syntactic priming electrophysiologically (though cf. Hasting, Kotz, and Friederici 2007, Ledoux et al., 2014, and Tooley et al. 2014, for earlier imaging work in younger adults). Both age groups showed priming and boost effects as attentuations of N400 and P600 effects on Target Verbs and Target Nouns. This effect is, however, only partly in line with findings reported by Ledoux, Traxler, and Swaab (2007), who found attenuations primarily on the disambiguating "by" – our effects were more robust on other sentence elements, which is discussed further below. No age-related differences on the strength of verbal and nominal N400s and P600s were found, indicating that both groups were susceptible to syntactic priming and that this may be recorded on ERPs.

The inclusion of the Lexical Control Condition (LCC; where verbs from the Prime were either repeated or not) points to an intriguing difference: older adults did *not* read repeated verbs faster than unrepeated verbs in Second Fillers, and electrophysiological differences between age groups on LCC Verbs were also apparent, but they *did* exhibit a lexical boost effect on both reading times and ERPs, which also consists of verb repetition. This occurred in spite of the fact more fillers intervened between Prime and Target than between Prime and Second Fillers. It could therefore be the case that syntactic overlap facilitates lexical processing in older adults, or at the very least facilitates recognition of verbal information, even across several intervening sentences. Past research has also emphasized the compensatory nature of older adults' cognition (e.g., Tomaszewski Farias et al. 2018) – that is, declining performance in one area of cognition is compensated for by conscious and unconscious strategies based on age-invariant cognitive functions. Some authors have extended this line of thought to language. For instance, Zhu, Hou, and Yang (2018) older adults place greater reliance on predictive processing in the presence of lexical-semantic impairments (though cf. Federmeier 2007). Following this account, our older sample could have experienced greater lexical processing facilitation in predictable contexts: given that reduced relative structures were the single most frequently read grammatical type in our experiment while second fillers comprised random, unrelated sentence types, the predictability of reduced relatives would have been greater than that of second filler items. Syntactic context – and potentially the prediction thereof – could, then, have benefited older adults' lexical processing.

Behavioral syntactic priming effects did not differ by group, unlike LCC patterns. However, as mentioned above, differences between groups became apparent on some – though not all – ERP measures. First of all, the distribution of ERP effects differed slightly between age groups. While P600 effects were front-left centered in younger adults, the older group exhibited a wider frontal distribution, including some front-right channels. A wider spread of scalp activation is a well-attested finding in older adults (Leckey and Federmeier 2020; Peelle 2019), and may again be tied into increasing reliance on compensation strategies in older age. For example, Manenti et al. (2013) found older adults exhibited wider prefrontal activation on transcranial magnetic stimulation measures to compensate for declines in naming ability and lexical access. In addition, Wingfield and Grossman (2006) interpreted more widespread functional magnetic resonance imaging activation in older compared to younger adults during processing of long and complex syntactic structures as a syntactic compensation effect (see further Diaz, Rizio, and Zhuang 2016, for a review). However, while the current study could add some evidence to these compensation strategy accounts, it is important to consider the relatively small sample size included in this study, as well as the unexpected distribution of some of our reported ERP components. Moreover, distributions of neuroelectric activity on the scalp may not necessarily be tied to directly underlying generators (e.g., McCarthy & Wood, 1985; Urbach & Kutas, 2002). We therefore interpret these distributions with some caution.

Additionally, age-related differences became apparent on ERPs in response to LCC trials. Intriguingly, while older adults did not show behavioral facilitation in response to lexis-only repetition, but younger adults did, the opposite pattern was observed in our ERP analysis. The Older group showed expected N400 attentuations in response to repeated compared to unrepeated trials, but the Younger group exhibited a sustained positivity for unrepeated compared to repeated trials (see Figure 7). In our Older group, therefore, while the neural processes underlying lexis-only effects were intact, these processes were not borne out behaviorally. This provides more evidence for the notion that syntactic effects facilitate lexical processing in older adults, and that the absence of syntactic facilitation causes older adults' behavioral responses to lexical effects to waver. An accurate theory of compensatory mechanisms in older adults should therefore consider the interaction of lexical and syntactic information, as this study showed clear differences in the use of cues from either domain by Older readers.

4.2 Implications for Syntactic Comprehension Priming and ERPs

The current study uncovered several effects which have important implications for the understanding of syntactic priming in comprehension and in relation to ERP research. Importantly, this study suggests syntactic priming in comprehension can be recorded independently from lexical overlap on both behavioral and ERP measures. This counters past suggestions of comprehension priming effects being reliant on lexical overlap (for a review, see Tooley and Traxler 2010), and concurs with the few investigations which have similarly found syntactic comprehension priming in ERPs (e.g., Ledoux, Traxler, and Swaab 2007; Tooley, Traxler, and Swaab 2009). Nevertheless, several unexpected patterns emerged in our data which warrant discussion.

Disambiguation effects on "by" in reduced relatives were not as robust as expected, or as found by Ledoux, Traxler, and Swaab (2007). While effects were present at "by", stronger patterns emerged on preceding Target Verbs and successive Target Nouns. Past results may explain why our findings of these Verbal and Nominal P600s were more sensitive to syntactic priming. Attenuations as a result of syntactic re-analysis may not always be captured solely at the initial point of disambiguation or structure-building (in our case, the "by"): Gouvea et al. (2010) summarise the P600 occurs at key syntactic structure building stages in a the sentence, including points of clause integration and verb presentation (see further Frisch et al., 2002; Kaan et al. 2000). Following this account, our findings of Verbal and Nominal effects are not entirely surprising: the main verb in our Targets is the point at which syntactic relations between constituents begin to be constructed (e.g., "The parents worried by the teenager decided to talk to him"), and the Noun is where a definite, final choice for disambiguation towards a reduced relative interpretation is made. Take, for instance, “The parents worried by the door after hearing the noise”. While disambiguation occurs at “by”, a determined choice for a reduced relative interpretation may, perhaps, only be made at the following noun. Finding syntactic priming effects at this noun therefore becomes less surprising.

Given that syntactic priming in comprehension reflects a general facilitation of syntactic processing (potentially due to various causes), it is unsurprising that integration of the reduced relative clause is also affected by this facilitation. Additionally, a more recent investigation by Tooley et al. (2014) using similar stimuli to the Ledoux et al. study completely failed to find P600 effects to “by” in reduced relative items, suggesting our findings of a weaker effect there are not unique. Instead, Tooley et al. (2014) They similarly focus on analyses of verbal and nominal ERPs. The larger, general finding of modulations in response to preceding reduced relative structures on other parts of the clause should, following Tooley et al., suggest syntactic priming did occur as expected.

The P600 effects we did find showed a frontal distribution as opposed to the traditionally-recognized centro-parietal topgraphy. Leckey and Federmeier (2020) summarize evidence suggesting the P600 may shift from a centro-parietal distribution to a frontal topography in older adults especially. Furthermore, Guillem et al. (1995) make the suggestion that frontal P600 components, as opposed to the posterior P600, are related to recognition. This account could explain our data: it is not unlikely that syntactic comprehension priming (and especially the lexical boost, where we found Verbal P600s) is to some extent related to recognizing words and patterns. Possibly, priming in comprehension could be more directly related to recognition than in production, and the lack of studies investigating the links between recognition and priming is therefore not surprising, given that the vast majority of syntactic priming studies have focused on production. This study offers tentative evidence for the role of recognition to syntactic priming in comprehension, and suggests future investigations into effects of recognition could be extremely fruitful.

Furthermore, he P600 on Target Nouns was modulated by Priming Condition in the opposite direction to our expectations. This effect is difficult to tie into the findings of past studies of syntactic priming using ERPs, or into the recognition-based account described above. In our results, Boosted trials evoked *more* positivity than Primed and Unprimed trials. A repeated main verb therefore led to larger effects on the subsequent noun. It is not immediately clear why this was the case. Effects of verb recognition may have carried over to the subsequent noun (given that the temporal delay between Target Verbs and Nouns was small, separated only by reading of “by”). Nevertheless, this effect manifested as a *reduction* of P600 amplitude on Verbs, whereas we observed an *increase* on Nouns. Alternatively, P600 effects have been shown to increase as a function of expectedness and predictiveness (e.g., Brothers et al. 2020), which we did not control for in this study. Given the relative novelty of this finding, we suggest a subsequent investigation into ERP effects on specific elements in Target nouns would be highly worthwhile.

The relation between our behavioral and ERP findings therefore warrants some attention. Effects of syntactic priming and lexical boost on reading times were roughly in line with ERP effects, as both methods found effects in and around the disambiguating ‘by’ and preceding and subsequent words. However, the manipulation of lexis-only overlap in second fillers (our Lexical Control Condition, or LCC) points to a dissociation between behavioral and ERP findings: only younger adults showed facilitatory effects of the LCC on reading times, while only older adults showed facilitatory effects on ERPs. Our data do not allow for the making of general conclusions about dissociations between ERP and behavioral data; this difference occurring in the one condition where *only* lexical material was manipulated is nevertheless of interest. It could be the case that older adults showed some implicit sensitivity to lexical repetition, but this sensitivity was not manifested in behavioral responses. This could be tied to ubiquitous findings of slowed lexical operations in aging (Cerella and Fozard 1984; Stern et al. 1991; Carroll et al. 2016; Hardy, Segaert, and Wheeldon 2020). That said, the current study did not focus on lexical access specifically, and future research on lexis in aging is necessary to elucidate this possibility.

Finally, this study assumes syntactic priming is a reliable index of syntactic processing in general. We suggest measuring syntactic priming allows for the effective investigation of processing in the absence of declarative memory demands (see further van Boxtel and Lawyer 2023), and that priming is therefore a potentially more accurate measurement of processing than traditional paradigms such as paragraph comprehension. Nevertheless, it must be acknowledged that syntactic priming does not equate to processing linearly. While past research has shown the mechanisms which underpin priming are essential to human communication and adaptation to interlocutors (Jaeger and Snider 2013; Hartsuiker and Pickering 2008), a fully rounded view of older adults' language processing strategies would necessarily have to include multiple measures of processing. Following the current findings, these other measures should preferably avoid (or intentionally control for) declarative memory demands and include neuroimaging measures. Potential paradigms which may prove useful in the study of older adults' language could include reading studies of syntactic integration and clause disambiguation, eye-tracking studies of unconscious parsing strategies, and analyses of fluent narrative. Indeed, some past studies have yielded highly informative findings using these implicit techniques (see for instance Emmorey et al. 1995; Antonenko et al. 2013; Beese et al. 2019).

Overall, this study supports past findings of lexically-independent syntactic priming in comprehension. Both priming and lexical boost effects were evident on ERP measures, although we did observe age-related differences in topography. The expected centro-parietal P600 component took a frontal topography (front-left in younger adults), while verbal N400s were captured in a broad parietal topography in both groups. A number of surprising ERP effects were uncovered, including increases of P600 amplitude on Target Nouns when verbs were repeated, which warrant further attention in future studies. Differences between Older and Younger adults were not found on reading times except for measures of lexis-only overlap, where Older adults were not facilitated. ERP measures further showed robust syntactic priming patterns in both age groups.

In conclusion, we make the case for a substantial nuancing of linguists' dominant views of the aging process. We find no evidence for a general decline in the efficiency or quality of the language processing system. From the literature this study discussed to its own findings, patterns of age-related declines in language processing appear largely influenced by the measures used and the explicit and implicit memory dynamics underylying language tasks. Perhaps more profoundly, we suggest linguists and psychologists should be aware of the multifaceted nature of aging, and should adjust hypotheses and paradigms accordingly, rather than assume that all of cogniton and all of language declines linearly. Perhaps, then, great age is indeed associated with great wisdom.

Ethics statement

Participants provided informed consent before taking part. Procedures outlined in this manuscript received approval from the University of Essex Social Sciences Ethics Sub-Committee.

Conflict of interest

The authors have no conflict of interest to declare.

References

Al Abed, Alice Shaam, Azza Sellami, Mylene Potier, Eva-Gunnel Ducourneau, Pauline Gerbeaud-Lassau, Laurent Brayda-Bruno, Valerie Lamothe, Nathalie Sans, Aline Desmedt, Peter Vanhoutte, et al. 2020. “Age-related impairment of declarative memory: linking memorization of temporal associations to glun2b redistribution in dorsal ca1.” *Aging Cell* 19 (10): E13243. https://doi.org/10.1111/acel.13243.

Alwin, Duane F., and Scott M. Hofer. 2011. “Health and cognition in aging research.” *Journals of Gerontology Series B: Psychological Sciences and Social Sciences* 66:I9–i16. https://doi.org/10.1093/geronb/gbr051.

Antonenko, Daria, Jens Brauer, Marcus Meinzer, Anja Fengler, Lucia Kerti, Angela D. Friederici, and Agnes Flöel. 2013. “Functional and structural syntax networks in aging.” *NeuroImage* 83:513–523. https://doi.org/10.1016/j.neuroimage.2013.07.018.

Bates, Douglas, Martin Mächler, Ben Bolker, and Steve Walker. 2015. “Fitting linear mixed-effects models using lme4.” *Journal of Statistical Software* 67 (1). https://doi.org/10.18637/jss.v067.i01.

Beese, Caroline, Markus Werkle-Bergner, Ulman Lindenberger, Angela D. Friederici, and Lars Meyer. 2019. “Adult age differences in the benefit of syntactic and semantic constraints for sentence processing.” *Psychology and Aging* 34 (1): 43. https://doi.org/10.1037/pag0000300.

Bock, J. Kathryn. 1986. “Syntactic persistence in language production.” *Cognitive Psychology* 18 (3): 355–387. https://doi.org/10.1016/0010-0285(86)90004-6.

Bopp, Kara L., and Paul Verhaeghen. 2005. “Aging and verbal memory span: a meta-analysis.” *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences* 60 (5): 223–233. https://doi.org/10.1093/geronb/60.5.P223.

Brothers, Trevor, Eddie W. Wlotko, Lena Warnke, and Gina R. Kuperberg. 2020. “Going the extra mile: effects of discourse context on two late positivities during language comprehension.” *Neurobiology of Language* 1 (1): 135–160. https://doi.org/10.1162/nol_a_00006.

Brunia, Cornelis H. M., Geert J. M. Van Boxtel, and Koen B. E. Böcker. 2011. "Negative slow waves as indices of anticipation: the bereitschaftspotential, the contingent negative variation, and the stimulus-preceding negativity." In *The Oxford handbook of event-related potential components,* edited by Steven J. Luck and Emily S. Kappenman. Oxford (UK): Oxford University Press. https://doi.org/10.1093/oxfordhb/9780195374148.013.0108.

Brysbaert, Marc. 2019. "How many words do we read per minute? A review and meta-analysis of reading rate." *Journal of Memory and Language* 109:104047. https://doi.org/10.1016/j.jml.2019.104047.

Bürkner, Paul-Christian. 2017. "'brms': an R package for bayesian multilevel models using stan." *Journal of Statistical Software* 80:1–28. https://doi.org/10.18637/jss.v080.i01.

Carroll, Rebecca, Anna Warzybok, Birger Kollmeier, and Esther Ruigendijk. 2016. "Age-related differences in lexical access relate to speech recognition in noise." *Frontiers in Psychology* 7:990. https://doi.org/10.3389/fpsyg.2016.00990.

Cerella, John, and James L. Fozard. 1984. "Lexical access and age." *Developmental Psychology* 20 (2): 235. https://doi.org/10.1037/0012-1649.20.2.235.

Chang, Franklin. 2008. "Implicit learning as a mechanism of language change." *Theoretical Linguistics* 34 (2): 115–122. https://doi.org/10.1515/THLI.2008.009.

Chang, Franklin, Marius Janciauskas, and Hartmut Fitz. 2012. "Language adaptation and learning: getting explicit about implicit learning." *Language and Linguistics Compass* 6 (5): 259–278. https://doi.org/10.1002/lnc3.337.

Chen, Qingrong, Xiaodong Xu, Dingliang Tan, Jingjing Zhang, and Yuan Zhong. 2013. "Syntactic priming in chinese sentence comprehension: evidence from event-related potentials." *Brain and Cognition* 83 (1): 142–152. https://doi.org/10.1016/j.bandc.2013.07.005.

Cohen, Gillian. 1979. "Language comprehension in old age." *Cognitive Psychology* 11 (4): 412–429. https://doi.org/10.1016/0010-0285(79)90019-7.

Conway, Andrew R. A., Michael J. Kane, Michael F. Bunting, D. Zach Hambrick, Oliver Wilhelm, and Randall W. Engle. 2005. "Working memory span tasks: a methodological review and user's guide." *Psychonomic Bulletin & Review* 12:769–786. https://doi.org/10.3758/BF03196772.

Curran, Tim, Don M. Tucker, Marta Kutas, and Michael I. Posner. 1993. "Topography of the n400: brain electrical activity reflecting semantic expectancy." *Electroencephalography and Clinical Neurophysiology/Evoked Potentials Section* 88 (3): 188–209.

Daneman, Meredyth, and Patricia A. Carpenter. 1980. "Individual differences in working memory and reading." *Journal of Verbal Learning and Verbal Behavior* 19 (4): 450–466. https://doi.org/10.1016/S0022-5371(80)90312-6.

Daneman, Meredyth, and Philip M. Merikle. 1996. "Working memory and language comprehension: a meta-analysis." *Psychonomic Bulletin & Review* 3 (4): 422–433. https://doi.org/10.3758/BF03214546.

DeDe, Gayle. 2014. "Sentence comprehension in older adults: evidence for risky processing strategies." *Experimental Aging Research* 40 (4): 436–454. https://doi.org/10.1080/0361073X.2014.926775.

DeDe, Gayle, David Caplan, Karen Kemtes, and Gloria Waters. 2004. "The relationship between age, verbal working memory, and language comprehension." *Psychology and Aging* 19 (4): 601. https://doi.org/10.1037/0882-7974.19.4.601.

Delorme, Arnaud, and Scott Makeig. 2004. "Eeglab: an open source toolbox for analysis of single-trial eeg dynamics including independent component analysis." *Journal of Neuroscience Methods* 134 (1): 9–21. https://doi.org/10.1016/j.jneumeth.2003.10.009.

Diaz, Michele T., Avery A. Rizio, and Jie Zhuang. 2016. "The neural language systems that support healthy aging: integrating function, structure, and behavior." *Language and Linguistics Compass* 10 (7): 314–334. https://doi.org/10.1111/lnc3.12199.

Diener, Marc J. 2010. "Cohen's *d*." In *The Corsini encyclopedia of psychology,* edited by Irving B. Weiner and W. Edward Craighead. Hoboken (NJ): John Wiley & Sons. https://doi.org/10.1002/9780470479216.corpsy0200.

Ditman, Tali, Phillip J. Holcomb, and Gina R. Kuperberg. 2007. "An investigation of concurrent ERP and self-paced reading methodologies." *Psychophysiology* 44 (6): 927–935. https://doi.org/10.1111/j.1469-8986.2007.00593.x.

Drozdick, Lisa Whipple, Susan Engi Raiford, Dustin Wahlstrom, and Lawrence G. Weiss. 2018. "The Wechsler adult intelligence scale – fourth edition and the Wechsler memory scale – fourth edition." In *Contemporary intellectual assessment: theories, tests, and issues,* edited by D P Flanigan and E M McDonough, 486–511. New York (NY): Guilford.

Emmorey, Karen, Ursula Bellugi, Angela Friederici, and Petra Horn. 1995. "Effects of age of acquisition on grammatical sensitivity: evidence from on-line and off-line tasks." *Applied Psycholinguistics* 16 (1): 1–23. https://doi.org/10.1017/S0142716400006391.

Ergo, Kate, Esther de Loof, and Tom Verguts. 2020. "Reward prediction error and declarative memory." *Trends in Cognitive Sciences* 24 (5): 388–397. https://doi.org/10.1016/j.tics.2020.02.009.

Falkenstein, Michael, Jorg Hoormann, and Joachim Hohnsbein. 1999. "ERP components in go/nogo tasks and their relation to inhibition." *Acta Psychologica* 101 (2-3): 267–291. https://doi.org/10.1016/S0001-6918(99)00008-6.

Federmeier, Kara D. 2007. "Thinking ahead: the role and roots of prediction in language comprehension." *Psychophysiology* 44 (4): 491–505. https://doi.org/10.1111/j.1469-8986.2007.00531.x.

Franklin, Michael S., Joseph Dien, James H. Neely, Elizabeth Huber, and Lauren D. Waterson. 2007. "Semantic priming modulates the N400, N300, and N400RP." *Clinical Neurophysiology* 118 (5): 1053–1068. https://doi.org/10.1016/j.clinph.2007.01.012.

Frishkoff, Gwen A. 2007. "Hemispheric differences in strong versus weak semantic priming: evidence from event-related brain potentials." *Brain and Language* 100 (1): 23–43. https://doi.org/10.1016/j.bandl.2006.06.117.

Gouvea, Ana C., Colin Phillips, Nina Kazanina, and David Poeppel. 2010. "The linguistic processes underlying the P600." *Language and Cognitive Processes* 25 (2): 149–188. https://doi.org/10.1080/01690960902965951.

Gronau, Quentin F., Henrik Singmann, and Eric-Jan Wagenmakers. 2017. *bridgesampling: an R package for estimating normalizing constants.* ArXiv: 1710.08162. https://doi.org/10.48550/arXiv.1710.08162.

Grossman, Murray, Edgar Zurif, Christine Lee, Penny Prather, Julia Kalmanson, Matthew B. Stern, and Howard I. Hurtig. 2002. "Information processing speed and sentence comprehension in Parkinson's Disease." *Neuropsychology* 16 (2): 174. https://doi.org/10.1037/0894-4105.16.2.174.

Guillem, Francois, Bernard N'Kaoua, Alain Rougier, and Bernard Claverie. 1995. "Intracranial topography of event-related potentials (N400/P600) elicited during a continuous recognition memory task." *Psychophysiology* 32 (4): 382–392. https://doi.org/10.1111/j.1469-8986.1995.tb01221.x.

Harada, Caroline N., Marissa C. Natelson Love, and Kristen L. Triebel. 2013. "Normal cognitive aging." *Clinics in Geriatric Medicine* 29 (4): 737–752. https://doi.org/10.1016/j.cger.2013.07.002.

Hardy, Sophie M., Katherine Messenger, and Elizabeth A. Maylor. 2017. "Aging and syntactic representations: evidence of preserved syntactic priming and lexical boost." *Psychology and Aging* 32 (6): 588. https://doi.org/10.1037/pag0000180.

Hardy, Sophie M., Katrien Segaert, and Linda Wheeldon. 2020. "Healthy aging and sentence production: disrupted lexical access in the context of intact syntactic planning." *Frontiers in Psychology,* 257. https://doi.org/10.3389/fpsyg.2020.00257.

Hardy, Sophie M., Linda Wheeldon, and Katrien Segaert. 2020. "Structural priming is determined by global syntax rather than internal phrasal structure: evidence from young and older adults." *Journal of Experimental Psychology: Learning, Memory, and Cognition* 46 (4): 720. https://doi.org/10.1037/xlm0000754.

Hartley, Joellen T., Carrie C. Stojack, Thomas J. Mushaney, T. A. Annon, and Diane W. Lee. 1994. "Reading speed and prose memory in older and younger adults." *Psychology and Aging* 9 (2): 216–223. https://doi.org/10.1037/0882-7974.9.2.216.

Hartsuiker, Robert J., Sarah Bernolet, Sofie Schoonbaert, Sara Speybroeck, and Dieter Vanderelst. 2008. "Syntactic priming persists while the lexical boost decays: evidence from written and spoken dialogue." *Journal of Memory and Language* 58 (2): 214–238. https://doi.org/10.1016/j.jml.2007.07.003.

Hartsuiker, Robert J., and Martin J. Pickering. 2008. "Language integration in bilingual sentence production." *Acta Psychologica* 128 (3): 479–489. https://doi.org/10.1016/j.actpsy.2007.08.005.

Hasting, Anna S., Sonja A. Kotz, and Angela D. Friederici. 2007. “Setting the stage for automatic syntax processing: the mismatch negativity as an indicator of syntactic priming.” *Journal of Cognitive Neuroscience* 19 (3): 386–400. https://doi.org/10.1162/jocn.2007.19.3.386.

Heyselaar, Evelien, Katrien Segaert, Serge J.W. Walvoort, Roy P.C. Kessels, and Peter Hagoort. 2017. “The role of nondeclarative memory in the skill for language: evidence from syntactic priming in patients with amnesia.” *Neuropsychologia* 101:97–105. https://doi.org/10.1016/j.neuropsychologia.2017.04.033.

Heyselaar, Evelien, Linda Wheeldon, and Katrien Segaert. 2021. “Structural priming is supported by different components of nondeclarative memory: evidence from priming across the lifespan.” *Journal of Experimental Psychology: Learning, Memory, and Cognition* 47 (5): 820–837. https://doi.org/10.1037/xlm0000955.

Horn, John L., and Gary Donaldson. 1976. “On the myth of intellectual decline in adulthood.” *American Psychologist* 31 (10): 701–719. https://doi.org/10.1037/0003-066X.31.10.701.

Hoyer, William J., and Paul Verhaeghen. 2006. “Memory aging.” In *Handbook of the psychology of aging,* edited by James E Birren, K Warner Schaie, Ronald P Abeles, Margaret Gatz, Timothy A Salthouse, 209–232. Elsevier. https://doi.org/10.1016/B978-012101264-9/50013-6.

Huang, Hsu-Wen, Aaron M. Meyer, and Kara D. Federmeier. 2012. “A ‘concrete view’ of aging: event related potentials reveal age-related changes in basic integrative processes in language.” *Neuropsychologia* 50 (1): 26–35. https://doi.org/10.1016/j.neuropsychologia.2011.10.018.

Im Craik, Fergus, and Mark Byrd. 1982. “Aging and cognitive deficits: the role of attentional resources.” *Aging and Cognitive Processes,* 191–211. https://doi.org/10.1007/978-1-4684-4178-9_11.

Jaeger, T. Florian, and Neal E. Snider. 2013. “Alignment as a consequence of expectation adaptation: syntactic priming is affected by the prime’s prediction error given both prior and recent experience.” *Cognition* 127 (1): 57–83. https://doi.org/10.1016/j.cognition.2012.10.013.

Just, Marcel A., and Patricia A. Carpenter. 1992. “A capacity theory of comprehension: individual differences in working memory.” *Psychological Review* 99 (1): 122. https://doi.org/10.1037/0033-295X.99.1.122.

Kaan, Edith. 2007. “Event-related potentials and language processing: a brief overview.” *Language and Linguistics Compass* 1 (6): 571–591. https://doi.org/10.1111/j.1749-818X.2007.00037.x.

Kaan, Edith, Anthony Harris, Edward Gibson, and Phillip Holcomb. 2000. “The P600 as an index of syntactic integration difficulty.” *Language and Cognitive Processes* 15 (2): 159–201. https://doi.org/10.1080/016909600386084.

Kiefer, Markus, Matthias Weisbrod, Isabel Kern, Sabine Maier, and Manfred Spitzer. 1998. "Right hemisphere activation during indirect semantic priming: evidence from event-related potentials." *Brain and Language* 64 (3): 377–408. https://doi.org/10.1006/brln.1998.1979.

Kleiman, Evan. 2017. *Understanding and analyzing multilevel data from real-time monitoring studies: an easily-accessible tutorial using R.* PsyArXiv. September 24. https://doi.org/10.31234/osf.io/xf2pw.

Leckey, Michelle, and Kara D. Federmeier. 2020. "The p3b and p600 (s): positive contributions to language comprehension." *Psychophysiology* 57 (7): E13351. https://doi.org/10.1111/psyp.13351.

Ledoux, Kerry, Matthew J. Traxler, and Tamara Y. Swaab. 2007. "Syntactic priming in comprehension: evidence from event-related potentials." *Psychological Science* 18 (2): 135–143. https://doi.org/10.1111/j.1467-9280.2007.01863.x.

Lee, Michael D., and Eric-Jan Wagenmakers. 2014. *Bayesian cognitive modeling: a practical course.* Cambridge (UK): Cambridge University Press.

Liechti, Chris. 2016. "Pyserial documentation." *Versión: 3.4, October 2021,* https://buildmedia.readthedocs.org/media/pdf/pyserial/stable/pyserial.pdf.

Lopez-Calderon, Javier, and Steven J. Luck. 2014. "ERPLAB: an open-source toolbox for the analysis of event-related potentials." *Frontiers in Human Neuroscience* 8:213. https://doi.org/10.3389/fnhum.2014.00213.

Luck, Steven J. 2014. *An introduction to the event-related potential technique.* MIT Press.

Lüdecke, Daniel. 2015. *sjPlot: data visualization for statistics in social science.* R package version 1.9. https://CRAN.R-project.org/package=sjPlot.

MacDonald, Maryellen C., and Morten H. Christiansen. 2002. "Reassessing working memory: comment on just and Carpenter (1992) and Waters and Caplan (1996)." *Psychological Review* 109 (1): 35–54. https://doi.org/10.1037/0033-295X.109.1.35.

Malyutina, Svetlana, Anna Laurinavichyute, Maria Terekhina, and Yevgeniy Lapin. 2018. "No evidence for strategic nature of age-related slowing in sentence processing." *Psychology and Aging* 33 (7): 1045. https://doi.org/10.1037/pag0000302.

Manenti, Rosa, Michela Brambilla, Michela Petesi, Carlo Miniussi, and Maria Cotelli. 2013. "Compensatory networks to counteract the effects of ageing on language." *Behavioural Brain Research* 249:22–27. https://doi.org/10.1016/j.bbr.2013.04.011.

Manouilidou, Christina, Roberto G. de Almeida, George Schwartz, and N. P.V. Nair. 2009. "Thematic roles in Alzheimer's Disease: hierarchy violations in psychological predicates." *Journal of Neurolinguistics* 22 (2): 167–186. https://doi.org/10.1016/j.jneuroling.2008.10.002.

Mathôt, Sebastiaan, Daniel Schreij, and Jan Theeuwes. 2012. "Opensesame: an open-source, graphical experiment builder for the social sciences." *Behavior Research Methods* 44:314–324. https://doi.org/10.3758/s13428-011-0168-7.

MATLAB. 2021. *Version r2021a.* Natick (MA): Mathworks Inc.

Matzke, Dora, and Eric-Jan Wagenmakers. 2009. “Psychological interpretation of the ex-gaussian and shifted wald parameters: a diffusion model analysis.” *Psychonomic Bulletin & Review* 16:798–817. https://doi.org/10.3758/PBR.16.5.798.

Mecklinger, Axel, Herbert Schriefers, Karsten Steinhauer, and Angela D. Friederici. 1995. “Processing relative clauses varying on syntactic and semantic dimensions: an analysis with event-related potentials.” *Memory & Cognition* 23 (4): 477–494. https://doi.org/10.3758/BF03197249.

Morcom, Alexa M., and Wendy Johnson. 2015. “Neural reorganization and compensation in aging.” *Journal of Cognitive Neuroscience* 27 (7): 1275–1285. https://doi.org/10.1162/jocn_a_00783.

Norman, Suzanne, Susan Kemper, and Donna Kynette. 1992. “Adults’ reading comprehension: effects of syntactic complexity and working memory.” *Journal of Gerontology* 47 (4): 258–265. https://doi.org/10.1093/geronj/47.4.P258.

Pace, Amy, Rufan Luo, Kathy Hirsh-Pasek, and Roberta Michnick Golinkoff. 2017. “Identifying pathways between socioeconomic status and language development.” *Annual Review of Linguistics* 3:285–308. https://doi.org/10.1146/annurev-linguistics-011516-034226.

Payne, Brennan R., Sarah Grison, Xuefei Gao, Kiel Christianson, Daniel G. Morrow, and Elizabeth A. L. Stine-Morrow. 2014. “Aging and individual differences in binding during sentence understanding: evidence from temporary and global syntactic attachment ambiguities.” *Cognition* 130 (2): 157–173. https://doi.org/10.1016/j.cognition.2013.10.005.

Peelle, Jonathan E. 2019. “Language and aging.” In *The Oxford handbook of neurolinguistics,* edited by Greig I. De Zubicaray, Niels O. Schiller, and Jonathan E. Peelle, 294–316. Oxford (UK): Oxford University Press. https://doi.org/10.1093/oxfordhb/9780190672027.013.12.

Pickering, Martin J., and Holly P. Branigan. 1998. “The representation of verbs: evidence from syntactic priming in language production.” *Journal of Memory and Language* 39 (4): 633–651. https://doi.org/10.1006/jmla.1998.2592.

Pion-Tonachini, Luca, Ken Kreutz-Delgado, and Scott Makeig. 2019. “Iclabel: an automated electroencephalographic independent component classifier, dataset, and website.” *NeuroImage* 198:181–197. https://doi.org/10.1016/j.neuroimage.2019.05.026.

Poulisse, Charlotte, Linda Wheeldon, and Katrien Segaert. 2019. “Evidence against preserved syntactic comprehension in healthy aging.” *Journal of Experimental Psychology: Learning, Memory, and Cognition* 45 (12): 2290. https://doi.org/10.1037/xlm0000707.

R Core Team. 2013. *R: a language and environment for statistical computing.* Vienna (AT): R Foundation for Statistical Computing. https://www.R-project.org/.

Ramscar, Michael, Peter Hendrix, Cyrus Shaoul, Petar Milin, and Harald Baayen. 2014. “The myth of cognitive decline: non-linear dynamics of lifelong learning.” *Topics in Cognitive Science* 6 (1): 5–42. https://doi.org/10.1111/tops.12078.

Reifegerste, Jana, João Veríssimo, Michael D. Rugg, Mariel Y. Pullman, Laura Babcock, Dana A. Glei, Maxine Weinstein, Noreen Goldman, and Michael T. Ullman. 2021. “Early-life education may help bolster declarative memory in old age, especially for women.” *Aging, Neuropsychology, and Cognition* 28 (2): 218–252. https://doi.org/10.1080/13825585.2020.1736497.

Salthouse, Timothy A. 1991. “Mediation of adult age differences in cognition by reductions in working memory and speed of processing.” *Psychological Science* 2 (3): 179–183. https://doi.org/10.1111/j.1467-9280.1991.tb00127.x.

———. 1996. “The processing-speed theory of adult age differences in cognition.” *Psychological Review* 103 (3): 403. https://doi.org/10.1037/0033-295X.103.3.403.

Salthouse, Timothy A., and Renee L. Babcock. 1991. “Decomposing adult age differences in working memory.” *Developmental Psychology* 27 (5): 763. https://doi.org/10.1037/0012-1649.27.5.763.

Schaie, K. Warner. 1974. “Translations in gerontology: from lab to life: intellectual functioning.” *American Psychologist* 29 (11): 802. https://doi.org/10.1037/h0037434.

Statistics, UIf. 2012. “International Standard Classification of Education: ISCED 2011.” *UNESCO Institute for Statistics Montreal,* https://doi.org/10.15220/978-92-9189-123-8-en.

Stern, Catherine, Penny Prather, David Swinney, and Edgar Zurif. 1991. “The time course of automatic lexical access and aging.” *Brain and Language* 40 (3): 359–372. https://doi.org/10.1016/0093-934X(91)90135-N.

Stine-Morrow, Elizabeth A. L., Mary K. Loveless, and Lisa M. Soederberg. 1996. “Resource allocation in on-line reading by younger and older adults.” *Psychology and Aging* 11 (3): 475. https://doi.org/10.1037/0882-7974.11.3.475.

Thothathiri, Malathi, and Jesse Snedeker. 2008. “Syntactic priming during language comprehension in three-and four-year-old children.” *Journal of Memory and Language* 58 (2): 188–213. https://doi.org/10.1016/j.jml.2007.06.012.

Tomaszewski Farias, Sarah, Maureen Schmitter-Edgecombe, Alyssa Weakley, Danielle Harvey, Katherine G. Denny, Cheyanne Barba, Jason T. Gravano, Tania Giovannetti, and Sherry Willis. 2018. “Compensation strategies in older adults: association with cognition and everyday function.” *American Journal of Alzheimer’s Disease & Other Dementias* 33 (3): 184–191. https://doi.org/10.1177/1533317517753361.

Tooley, Kristen M., Martin J. Pickering, and Matthew J. Traxler. 2019. “Lexically-mediated syntactic priming effects in comprehension: sources of facilitation.” *Quarterly Journal of Experimental Psychology* 72 (9): 2176–2196. https://doi.org/10.1177/1747021819834247.

Tooley, Kristen M., Tamara Y. Swaab, Megan A. Boudewyn, Megan Zirnstein, and Matthew J. Traxler. 2014. "Evidence for priming across intervening sentences during on-line sentence comprehension." *Language, Cognition and Neuroscience* 29 (3): 289–311. https://doi.org/10.1080/01690965.2013.770892.

Tooley, Kristen M., and Matthew J. Traxler. 2010. "Syntactic priming effects in comprehension: a critical review." *Language and Linguistics Compass* 4 (10): 925–937. https://doi.org/10.1111/j.1749-818X.2010.00249.x.

Tooley, Kristen M., Matthew J. Traxler, and Tamara Y. Swaab. 2009. "Electrophysiological and behavioral evidence of syntactic priming in sentence comprehension." *Journal of Experimental Psychology: Learning, Memory, and Cognition* 35 (1): 19. https://doi.org/10.1037/a0013984.

Touzalin-Chretien, Pascale, Solange Ehrler, and André Dufour. 2010. "Dominance of vision over proprioception on motor programming: evidence from ERP." *Cerebral Cortex* 20 (8): 2007–2016. https://doi.org/10.1093/cercor/bhp271.

Traxler, Matthew J. 2008. "Lexically independent priming in online sentence comprehension." *Psychonomic Bulletin & Review* 15 (1): 149–155. https://doi.org/10.3758/PBR.15.1.149.

Traxler, Matthew J., Kristen M. Tooley, and Martin J. Pickering. 2014. "Syntactic priming during sentence comprehension: evidence for the lexical boost." *Journal of Experimental Psychology: Learning, Memory, and Cognition* 40 (4): 905–918. https://doi.org/10.1037/a0036377.

van Boxtel, Willem S. 2021. *Supplementary material for 'In the prime of life: ERP evidence for syntactic comprehension priming in older adults'.* Created 2021-12-14, updated 2023-06-30. OSFHOME. https://osf.io/3yrnv/.

van Boxtel, Willem S., and Laurel A. Lawyer. 2023. "Syntactic comprehension priming and lexical boost effects in older adults." *Language, Cognition and Neuroscience* 38 (1): 105–120. https://doi.org/10.1080/23273798.2022.2091151.

Verhaeghen, Paul. 2003. "Aging and vocabulary score: a meta-analysis." *Psychology and Aging* 18 (2): 332–339. https://doi.org/10.1037/0882-7974.18.2.332.

Warren-Leubecker, Amye, and Beth Warren Carter. 1988. "Reading and growth in metalinguistic awareness: relations to socioeconomic status and reading readiness skills." *Child Development,* 728–742. https://doi.org/10.2307/1130572.

Waters, Gloria S., and David Caplan. 1996. "The capacity theory of sentence comprehension: critique of Just and Carpenter (1992)." *Pschological Review* 103 (4): 761–772. https://doi.org/10.1037/0033-295X.103.4.761.

———. 2001. "Age, working memory, and on-line syntactic processing in sentence comprehension." *Psychology and Aging* 16 (1): 128–144. https://doi.org/10.1037/0882-7974.16.1.128.

Wechsler, David. 1955. "Wechsler adult intelligence scale." *Archives of Clinical Neuropsychology,* https://doi.org/10.1037/t15169-000.

Wingfield, Arthur, and Murray Grossman. 2006. “Language and the aging brain: patterns of neural compensation revealed by functional brain imaging.” *Journal of Neurophysiology* 96 (6): 2830–2839. https://doi.org/10.1152/jn.00628.2006.

Zhu, Zude, Xiaopu Hou, and Yiming Yang. 2018. “Reduced syntactic processing efficiency in older adults during sentence comprehension.” *Frontiers in Psychology* 9:243. https://doi.org/10.3389/fpsyg.2018.00243.

5 Appendix A: Model Tables

Table 3: Linear Mixed Model summary of residualized reading times in Target ROIs. Est denotes parameter estimate, SE equals standard error, DF denotes degrees of freedom. Values meeting the significance threshold of *p*=.05 are represented in bold. Effect sizes are given as Cohen’s *d* (Diener 2010).

ROI	*Predictor*	*Est.*	*SE*	*DF*	*T*	*P*	*D*
By	Intercept	4.7430	.0497	26			
	Priming	-.0223	.0268	99	-.830	.408	-.167
	Boost	-.0062	.0276	98	-.231	.810	-.047
	Age Group	-.2854	.0125	3012	-22.932	**<.001**	-.836
	RST	-.0365	.0074	2981	-4.902	**<.001**	-.180
	LCT	.0897	.0075	2988	11.983	**<.001**	.438
	Priming * Group	.0128	.0130	3004	.981	.327	.036
	Boost * Group	.0063	.0128	3004	.492	.627	.018
	Priming * RST	-.0130	.0059	3004	-2.193	**.028**	-.080
	Boost * RST	-.0052	.0058	3003	-.883	.378	-.032
	Priming * LCT	-.0009	.0060	3003	-.015	.988	.000
	Boost * LCT	-.0012	.0059	3003	-.211	.833	-.008
Spillover	Intercept	4.7130	.0582	33			
	Priming	-.1107	.0396	93	-2.797	**.006**	-.579
	Boost	-.1503	.0395	93	-3.803	**<.001**	-.788
	Age Group	-.3254	.0138	3019	-23.621	**<.001**	-.860
	RST	-.0402	.0082	2977	-4.884	**<.001**	-.179
	LCT	.0687	.0083	2986	8.312	**<.001**	.304
	Priming * Group	.0096	.0144	3017	.666	.506	.024
	Boost * Group	-.0140	.0142	3017	-.986	.324	-.036
	Priming * RST	-.0069	.0065	3017	-1.052	.293	-.038
	Boost * RST	.0024	.0065	3017	.374	.708	.014
	Priming * LCT	-.0131	.0066	3017	-1.982	**.048**	-.072
	Boost * LCT	-.0048	.0065	3017	-.737	.461	-.027

Table 4: Linear Mixed Model summary of residualized reading times in LCC ROIs. Est denotes parameter estimate, SE equals standard error, DF denotes degrees of freedom. Values meeting the significance threshold of p=.05 are represented in bold. Effect sizes are given as Cohen's d (Diener 2010).

ROI	*Predictor*	*Est.*	*SE*	*DF*	*T*	*P*	*D*
Verb	Intercept	4.1660	.0690	52			
	Repetition	-.0643	.0480	47	-1.339	.187	-.393
	Age Group	-.2758	.0242	1462	-11.409	**<.001**	-.597
	RST	-.0490	.0142	1375	-3.435	**.001**	-.185
	LCT	.0706	.0143	1392	4.934	**<.001**	.265
	Repetition * Group	.0222	.0182	1489	1.223	.223	.063
	Repetition * RST	-.0093	.0083	1489	-1.116	.265	-.058
	Repetition * LCT	-.0025	.0084	1489	-.300	.764	-.016
Spillover	Intercept	4.6880	.0654	56			
	Repetition	.0264	.0483	46	.546	.588	-.162
	Age Group	-.0276	.0209	1479	-13.202	**<.001**	-.687
	RST	-.0343	.0123	1413	-2.777	**.006**	-.148
	LCT	.0633	.0128	1427	5.111	**<.001**	-.271
	Repetition * Group	.0371	.0157	1490	2.365	**.018**	.122
	Repetition * RST	-.0007	.0072	1490	-.094	.925	-.005
	Repetition * LCT	-.0133	.0072	1490	-1.848	.065	-.096

Table 5: Linear Mixed Model summary of residualized reading times in LCC ROIs. Est denotes parameter estimate, SE equals standard error, DF denotes degrees of freedom. Values meeting the significance threshold of p=.05 are represented in bold. Effect sizes are given as Cohen's d (Diener 2010).

	Est.	*SE*	*DF*	*T*	*P*	*D*
Intercept	-.093	.520	37			
Repetition	.784	.160	1272	4.900	**<.001**	.275
Age Group	1.187	.725	37	1.637	.11	.540
Repetition * Age Group	-2.117	.221	1271	-9.581	**<.001**	-.538

Table 6: Linear Mixed Model summary of mean EEG amplitude responses between 400 and 550 ms following onset of verbs in Targets (upper panel), and between 500 and 700 ms (lower panel). Models included a random effect for Participant. The posterior negativity model directly contrasted Primed v Boosted trials to examine the lexical boost, while the more exploratory frontal positivity model included all three Priming Condition levels and thus shows contrasts for both abstract priming (Unprimed v Primed) and the lexical boost. Est denotes parameter estimate, SE equals standard error, DF denotes degrees of freedom. Values meeting the significance threshold of p=.05 are represented in bold. Effect sizes are given as Cohen's *d*.

ROI		*Est.*	*SE*	*DF*	*T*	*P*	*D*
400-550 ms (Posterior)	Intercept	.619	.522	37			
	Priming Condition	-.633	.157	1270	-4.037	**<.001**	-.227
	Age Group	-1.068	.730	37	-1.463	.152	-.484
	Priming Condition * Age Group	.204	.220	1270	.927	.354	.052
500-600 ms (Frontal)	Intercept	2.995	.585	35			
	Abstract Priming	.595	.105	1957	5.691	**<.001**	.257
	Lexical boost	.499	.105	1957	4.773	**<.001**	.216
	Age Group	-1.251	.816	35	-1.533	.134	-.518
	Abstract Priming * Age Group	-.165	.146	1957	-1.133	.257	-.051
	Lexical boost * Age Group	-.076	.146	1957	-.524	.600	-.024

Table 7: Linear mixed model summary of ERP responses between 500-700 ms following "by" in Targets. Est denotes parameter estimate, SE equals standard error, DF denotes degrees of freedom. Values meeting the significance threshold of *p*=.05 are represented in bold. Effect sizes are given as Cohen's *d* (Diener 2010).

	Est.	*SE*	*DF*	*T*	*P*	*D*
Intercept	1.078	.568	35.90			
Priming Condition	-.266	.136	1262.91	-1.961	.050	-.110
Age Group	-.537	.793	35.91	-.677	.502	-.226
Priming Condition * Age Group	.515	.192	1263.10	2.689	**.007**	.151

Table 8: Linear Mixed Model summary of mean EEG amplitude responses between 400 and 550 ms following onset of nouns in Targets (upper panel), and between 500 and 700 ms (lower panel). Models included a random effect for Participant. The posterior, early model contrasted unprimed trials vs primed and boosted trials, while the later frontal model included all three condition levels (unprimed, primed, boosted). Est denotes parameter estimate, SE equals standard error, DF denotes degrees of freedom. Values meeting the significance threshold of p=.05 are represented in bold. Effect sizes are given as Cohen's *d*.

ROI		*Est.*	*SE*	*DF*	*T*	*P*	*D*
400-550 ms (Posterior)	Intercept	.205	.486	35			
	Priming Condition	-.219	.054	1957	-4.068	**<.001**	-.184
	Age Group	-.144	.678	35	-.212	.834	-.072
	Priming Condition * Age Group	.017	.075	1957	.221	.825	.010
500-600 ms (Frontal)	Intercept	1.731	.573	35			
	Priming Condition	-3.59	.146	1957	-2.454	**.014**	-.104
	Age Group	-.417	.799	3500	-.522	.604	-.168